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AGRICULTURAL AVIATION STUDY

AND

PROGRAM PLAN

VOLUME II

SUPPLEMENTAL INFORMATION

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9 JUNE 1976

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
OFFICE OF AERONAUTICS AND SPACE TECHNOLOGY

AGRICULTURAL AVIATION STUDY

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PROGRAM PLAN

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FOREWORD

This is Volume II of a two-volume final report that presents:

- An assessment of the impact of agricultural aviation on agricultural productivity
- An assessment of the technology needs of agricultural aviation
- A proposed program plan by which NASA technology can be utlized to improve the performance of current agricultural aircraft.

Volume I—Project Summary, presents significant findings and recommendations in brief. Part I discusses the Ag-Air Study; Part II presents the Ag-Air Program Plan. Volume I is designed in a story-book format. Text on the right-hand pages complements the graphics and other information depicted on the left-hand pages.

Volume II—Supplemental Information, provides a more detailed presentation of the study results and of the program plan.

TABLE OF CONTENTS

		Page
	FOREWORD	i
	LIST OF FIGURES	v
	LIST OF TABLES	vii
I.	**INTRODUCTION**	1
	Background	1
	Purpose of The Study	1
	Volume II Outline	1
II.	**AGRICULTURAL CONCERNS AND DEVELOPMENTS**	3
	World Food Shortages	3
	World Supply of Arable Land	3
	U.S. Farm Picture	3
	U.S. Farm Receipts	5
	Summary	5
III.	**AG-AIR TODAY**	7
	Industry Profile—1974	7
	World Trends	9
	U.S. Trends	10
	Current Agricultural Aircraft Utility	10
	Economic Basis of Current Agricultural Aircraft Utilization	17
	Impact of Ag-Air on Agricultural Production	24
	Aerial Versus Ground Application	28
	Impact of No-Till Farming on Ag-Air	29
IV.	**PROBLEMS ASSOCIATED WITH AG-AIR**	31
	Aircraft Design and Performance Characteristics	31
	Dispersal System and Flow Field Characteristics	33
	Operating Constraints	34
	Safety of Personnel	35
V.	**NASA ROLE IN AG-AIR**	37
	Applicable NASA Research and Technology	37
	NASA Special Skills and Facilities	37
	Potential Benefits of NASA R&T	39
VI.	**PRELIMINARY AG-AIR R&T PROGRAM PLAN**	41
	Background	41
	Program Goals and Objectives	41
	Overall Program Approach	41
	Representative Research Areas	41
	Functional Program Organization	45
	Overview of Technical Plan	45
	Center Subsystem Research Areas	45
	Program Budget Summary	45
	Potential Benefits of Proposed Program Plan	45
	Potential Recipients of Program Benefits	59
VII.	**SUMMARY AND NEXT STEPS**	63
	Ag-Air Study	63
	Ag-Air Program Plan	63
	Next Steps	63
APPENDIX A: Aviation Data Base Support for Ag-Air Program Planning		65

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LIST OF FIGURES

		Page
1.	World Farm Productivity—Grain Production—1972	4
2.	World Supply of Arable Land	4
3.	U.S. Farm Picture 1940-1974	5
4.	U.S. Farm Market Receipts 1970-1974	5
5.	U.S. Agricultural Aviation Profile	8
6.	Cost and Supply Curves for Ag-Air Services	22
7.	Demand for Ag-Air Services at Different Elasticities	23
8.	Kinked Demand Curve for Ag-Air Services	23
9.	Growth in No-Till Farming	30
10.	Problems in Agricultural Aviation	32
11.	Agricultural Aviation Problem Areas and Applicable NASA Research and Technology	38
12.	Program Goals and Objectives	42
13.	Overall Program Approach	43
14.	Aircraft Subsystem Research	44
15.	Dispersal System Research	46
16.	Flow Field Research	47
17.	Functional Program Organization	48
18.	Overview of Technical Plan	49
19.	Center Subsystem Research Areas	50
20.	Program Budget Summary	51
21.	Effect of Increase in Ferry Speed on Productivity	53
22.	Effect of Application Speed on Productivity	53
23.	Effect of Increase in Swath Width on Productivity	54
24.	Effect of Decrease in Application Rate on Productivity	54
25.	Potential Soybean Total Yield Increases with Fungicide Application	58
26.	Potential Net Additional Return to Growers after Fungicide Treatments	58
27.	Potential Total Yield of U.S. Potato Crop if Aerial Application Methods Employed	59
28.	Potential Additional Income if Aerial Application Methods Employed	59
29.	Farm Production Regions	62
A.1	Gross National Product	66
A.2	Real Farm Business GNP	66
A.3	Agricultural Employment	67
A.4	Farm Residential Structure	67
A.5	Accidents	67
A.6	Airline Industry Rate of Return on Investment	67
A.7	Farm Proprietors Income	68
A.8	Acres Treated by Ag-Air	68
A.9	Projected Acres No-Till Farmed	68
A.10	Projected Acres Treated by Ag-Air	68

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LIST OF TABLES

		Page
1.	World-Wide Aircraft Use for Plant Seeding, Protection and Nutrition as well as Vector and Locust Control	9
2.	World Situation (1973)	10
3.	Agricultural Aviation Trends in the United States	11
4.	Trends in Material Forms and Uses of Aircraft Applications, Areas Treated, and Numbers of Aircraft	11
5.	Ag-Air Accident Rates	12
6.	General Aviation/Agricultural Aviation Accident Rates	12
7.	Shipments of Agricultural Aircraft 1970-1975	13
8.	Operating Costs for Class A ($70,000) Agricultural Aircraft	18
9.	Operating Costs for Class B ($35,000) Agricultural Aircraft	19
10.	Operating Costs for Class C ($20,000) Agricultural Aircraft	20
11.	Rate of Return on Stockholders' Equity for Selected U.S. Industries 1972	24
12.	Planted Acreage for Principal Crops (U.S.)	24
13.	Gross Farm Income (U.S.)	25
14.	Average U.S. Grain Yields, 1950-1974	25
15.	U.S. Expenditures for Fertilizer and Lime, 1959-1973	26
16.	U.S. Fertilizer Consumption, 1959-1973	26
17.	U.S. Farmworker Productivity Selected Years, 1959-1972	26
18.	Desirable Ag-Aircraft Characteristics	31
19.	Time Required to Treat Various Acreages	55
20.	Equipment Requirements	55
21.	Effect of Increased Productivity Rates on Acreages Treated	56
22.	10 Hour Output of Aircraft and Tractor at Increased Productivity Rates	56
23.	1973 Soybean Production—Southern Plains	57
24.	Groups Versus Perceived Needs	60
25.	Crops Currently Employing Aerial Application Services	60
26.	Principal Crops by Growing Regions	61
A.1	Aviation Data Base Variables Relevant to Ag-Air Study and Program Planning	65
A.2	Additional Variables Relevant to Ag-Air Program	65

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I. INTRODUCTION

BACKGROUND

In a letter to Congressman Barry M. Goldwater, Jr. on 12 March 1975, Mr. Everett H. Pingrey, Chairman of the Research and Development Committee, California Agricultural Aircraft Association, Inc., requested that a research effort be undertaken to improve agricultural aviation efficiency for American agriculture.[1] Included with the letter was a committee report which listed findings in support of a research effort. The findings also cited areas which could be of interest to and funded by NASA.

In November 1975, a high-level NASA working group undertook a study to investigate the potential for aviation technology advances to improve agricultural productivity.

Mr. Robert Price, NASA consultant, headed the study team and was assisted by other NASA technical representatives and by Operations Research, Inc. (ORI), Silver Spring, Maryland.

PURPOSE OF THE STUDY

The purpose of the study undertaken by ORI was to:

- Collect statistics relating to the agricultural aviation industry
- Summarize the impact of agricultural aircraft on U.S. and worldwide productivity
- Develop forecasts of future major roles for agricultural aircraft
- List major problems associated with agricultural aviation
- Recommend areas for aircraft and systems research efforts and prospective payoffs for that research
- Analyze the utility of existing NASA R&T programs as applied to the agricultural aviation area
- Prepare a program plan by which NASA technology can be utilized to improve the performance of current agricultural aircraft
- Prepare a briefing to describe the details of the program plan developed.

VOLUME II OUTLINE

As a prelude to the assessment of agricultural aviation (ag-air) technology needs, Chapter II discusses some overall agricultural concerns and developments.

Chapter III discusses ag-air today—its utility, economic basis, growth trends and impact on agricultural productivity—and the potential impact of new farming techniques on ag-air.

Some problems associated with ag-air are discussed in Chapter IV.

Chapter V discusses NASA's role in ag-air—the applicability of its ongoing Research and Technology (R&T) programs and its special skills and facilities.

A proposed NASA ag-air R&T program is presented in Chapter VI.

Finally, a discussion of some next steps, including comments regarding initial analyses to be conducted under the ag-air R&T program, is presented in Chapter VII.

Appendix A discusses the use of the NASA Aviation Date Base in support of ag-air planning.

[1] *World of Agricultural Aviation*, National Agricultural Aviation Association (NAAA), April 1975.

II. AGRICULTURAL CONCERNS AND DEVELOPMENTS

WORLD FOOD SHORTAGES

Agricultural productivity has increased considerably during the past two decades. Nevertheless, half the people in the world today do not have enough to eat and one out of every seven persons is starving.[1] Two factors point to potentially greater shortages. First, world population could increase 50 percent from the present 4 billion by the year 2000. Secondly, more than one third of the potential world harvest each year is destroyed by pests, plant diseases and weeds—an annual loss of $75 billion.[2]

World grain production varies considerably as indicated in Figure 1. India and China do not come close to supplying enough food for their populations. Farmers in those countries are barely feeding themselves.

To slow the trend of growing food shortages, significant increases in agricultural productivity are clearly mandatory.

WORLD SUPPLY OF ARABLE LAND

At the outset, a means for achieving increased agricultural output may appear to lie in increasing the amount of land under cultivation. However, in the book *Limits to Growth*,[3] the authors point out that the supply of arable land in the world is decreasing even as the population is increasing.

Depicted in Figure 2 are:

- The total world supply of arable land
- The agricultural land needed at present productivity levels
- Projections of arable land available for agriculture in the future
- The predicted effect of doubling present productivity levels.

Approximately one half of the world supply of arable land is currently in production. Remaining land will require immense capital inputs to reach, clear, irrigate or fertilize before it can produce food. According to a Food and Agricultural Organization report, it is not economically feasible to open more land to cultivation even given the pressing need today.

In the year 2000, the arable land needed (at present productivity levels) will exceed the land available. Doubling present productivity could delay the problem 50-60 years. Agricultural aviation (ag-air) can increase productivity by some smaller percentage and buy 10 to 20 years in which to develop additional solutions.

U.S. FARM PICTURE

Figure 3 depicts changes in the U.S. farm picture since 1940. Trends in U.S. farming are toward a less labor-intensive industry, smaller numbers of farms and larger farm acreages. Total acreage in cultivation is relatively constant. The trend toward larger farm acreages encourages the use of agricultural aircraft.

U.S. FARM RECEIPTS

Farm receipts are increasing (almost $100 billion in 1974) with livestock accounting for almost one half of

[1] "A Viable Agriculture and the Environment," *World of Agricultural Aviation*, NAAA, July 1975.

[2] "Provisional Indicative World Plan for Agricultural Development," *Food and Agricultural Organization*, Vol. 1, Rome: United Nations, 1970.

[3] Meadows, D. L. and Meadows, D. H., *Limits to Growth*, New American Library, New York, 1974.

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COUNTRY	PRODUCTION (TONS)	PERSONS IN AGRICULTURE	TOTAL POPULATION
UNITED STATES	239 MILLION	8 MILLION	209 MILLION
SOVIET UNION	200 MILLION	77 MILLION	247 MILLION
CHINA	168 MILLION	514 MILLION	800 MILLION
INDIA	105 MILLION	364 MILLION	563 MILLION

FIGURE 1. WORLD FARM PRODUCTIVITY—GRAIN PRODUCTION—1972

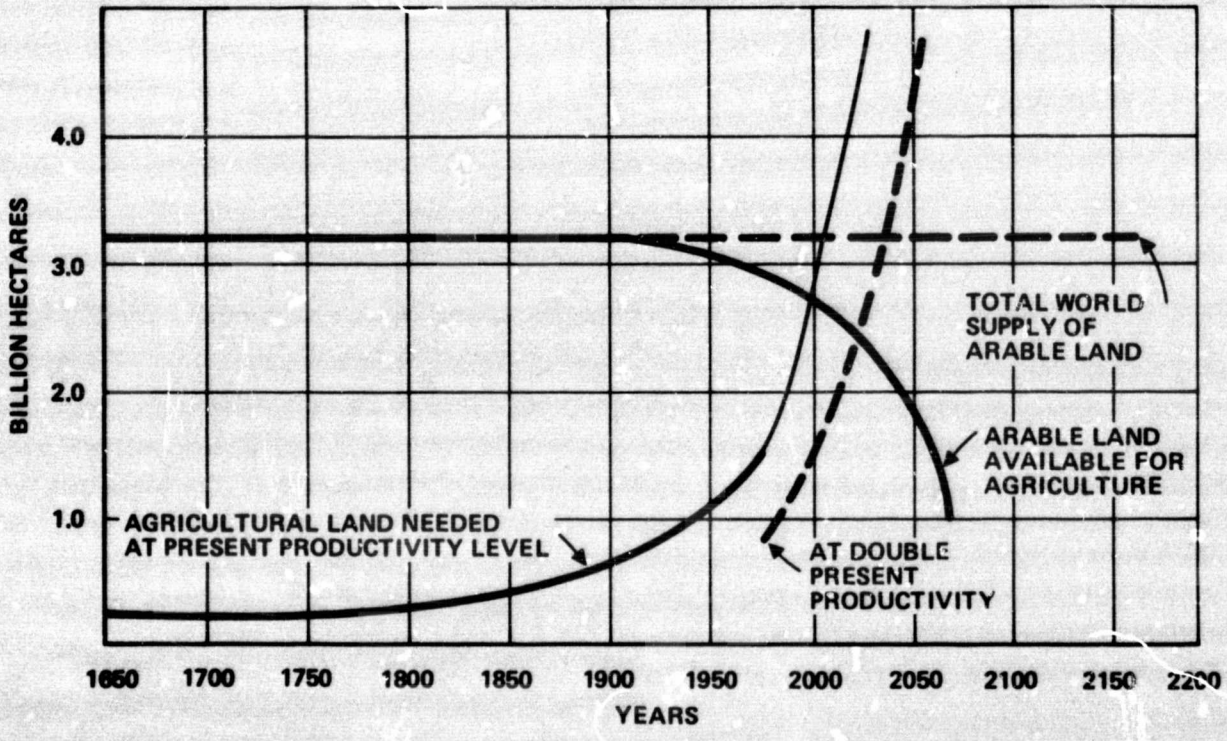


FIGURE 2. WORLD SUPPLY OF ARABLE LAND

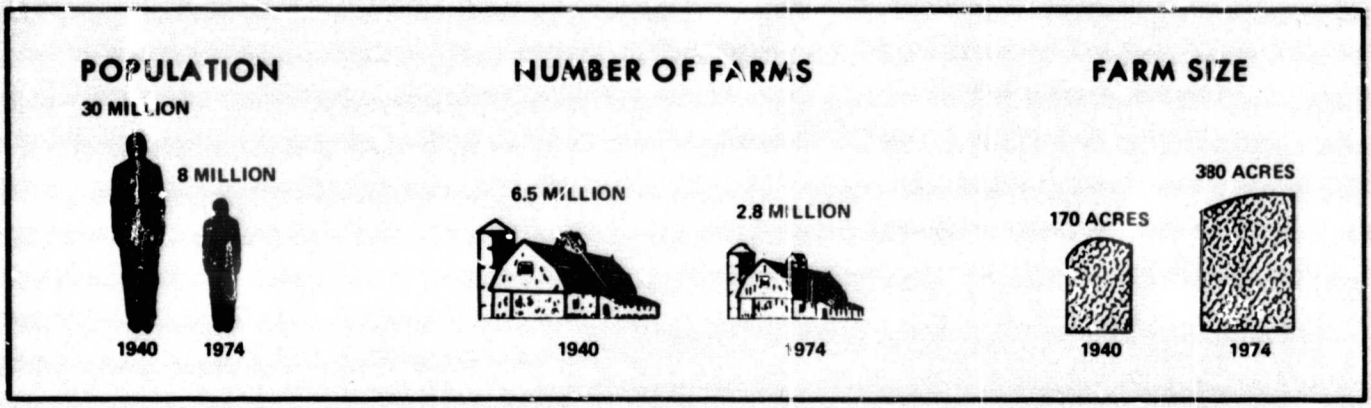


FIGURE 3. U.S. FARM PICTURE 1940-1974

the total, as indicated in Figure 4. Agricultural aviation can increase crop productivity and, by rangeland weed and pest control, also influence livestock productivity.

SUMMARY

Existing world food shortages, as well as predictions of even greater shortages in the future, clearly indicate a need for increased agricultural productivity. Agricultural aviation can contribute to increased agricultural productivity among livestock and crops, as will be demonstrated in subsequent sections of this report.

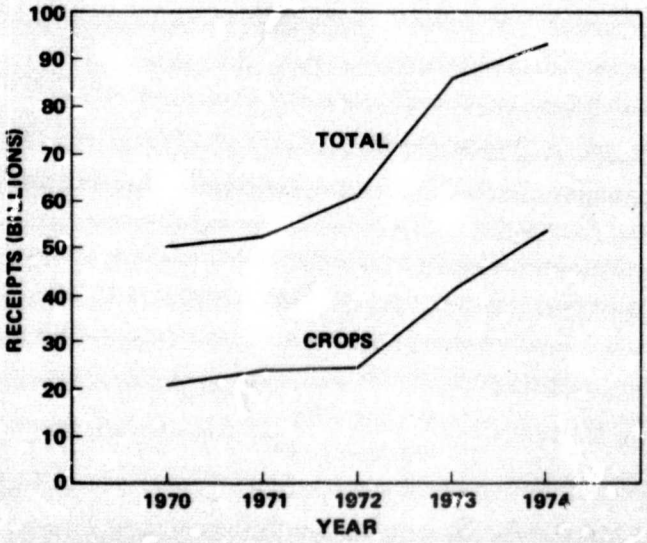


FIGURE 4. U.S. FARM MARKET RECEIPTS 1970-1974

III. AG-AIR TODAY

INDUSTRY PROFILE—1974

The agricultural aircraft industry is a healthy growing dynamic segment of American industry. Its impact on U.S. farm production and the economy of the country is quite large relative to the size of the industry. The potential impact is even larger.

The Research and Development Committee of the National Agricultural Aviation Association (NAAA) has performed an analysis which indicates that a 10 percent increase in farm production can be directly attributed to the use of aircraft.[1] This 10 percent increase represents remarkable leverage for an industry whose public image still draws pictures of white scarves and leather helmets.

The facts of the industry belie this image. Figure 5 presents a statistical profile of the industry as it existed in the United States in 1974. The data presented are in some cases approximate and developed by informed industry estimates.

The NAAA R&D Committee estimates[2] that there are approximately 16,000 agricultural aircraft operational in the world today and that nearly one half of these are operational in the United States. In 1974, approximately 1400 new production agricultural aircraft were produced in the United States, almost 45 percent of which were exported to foreign countries.

In 1974 in the United States, an estimated 200 million acres were treated by air for seeding, fertilizing, and agricultural chemicals. These total acres represent multiple applications to the same cropland since of the 350 million acres in cultivation in the United States, it is estimated that only 15 percent (52.5 million acres) benefit from aerial application.

A comparison[3] of the situation in the Soviet Union (the other major user of agricultural aircraft) in 1974 indicates that approximately 225 million acres were treated by air with 59 percent receiving fertilization treatments, 35 percent receiving herbicide treatments, and 6 percent receiving pesticide treatments. In the Soviet Union approximately 68 percent of all weed control and 38 percent of all plant protection is accomplished by air.

The estimated total revenues to U.S. operators for application only of agriculture chemicals were approximately $300 million. The aircraft manufacturers received approximately $50 million in 1974 revenues for agricultural aircraft. The cost of agricultural chemicals applied (by all methods) was approximately $6 billion in 1974. The percentage of this amount applied by aircraft is unknown at this time. A first order estimate could be obtained with the knowledge that about 15 percent of all acreage under cultivation in the United States received aerial treatment. However, the fertilizer cost represents $5 billion of the $6 billion total estimate for agricultural chemicals and in 1970 fertilizer represented only 7 percent of all aerial application (Table 3). Using similar percentages in 1974 led to estimates of between $200 million and $900 million for agricultural chemicals applied aerially. Thus, the total industry-generated revenues for chemicals, chemical applications, and for new aircraft were between $0.5 and $1.25 billion for 1974.

[1] *World of Agricultural Aviation*, National Agricultural Aviation Association (NAAA), April 1975.

[2] *Ibid.*

[3] Estimates supplied by Mr. V. A. Nazarov, Soviet Delegation Leader at the NAAA/NASA workshop on December 10, 1975.

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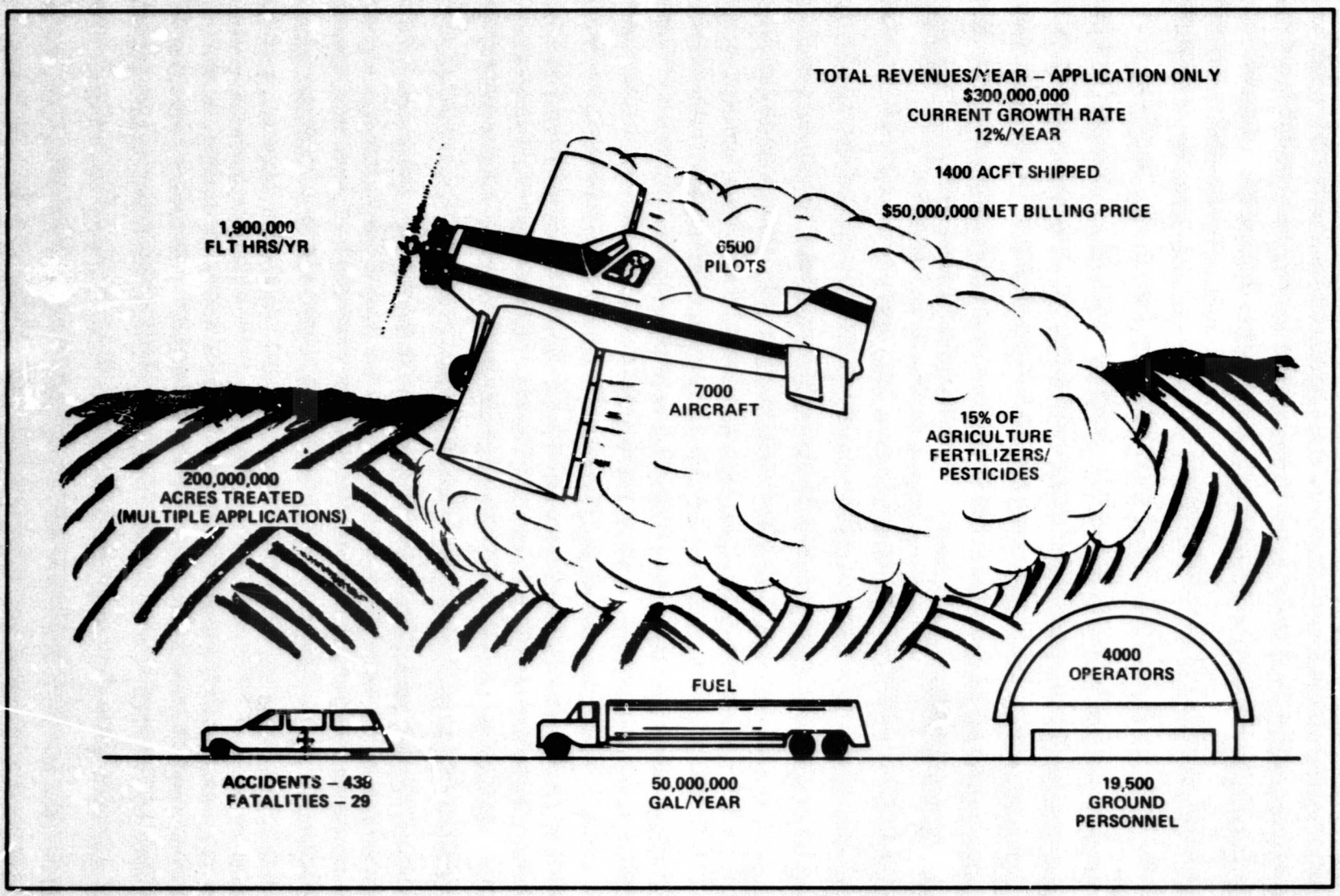


FIGURE 5. U.S. AGRICULTURAL AVIATION PROFILE

WORLD TRENDS

A detailed statistical profile of the industry is difficult to develop. However, a reasonably comprehensive picture of industry patterns has been generated. Table 1 presents the world-wide distribution of agricultural aircraft and the total area treated. Note that total area treated includes multiple applications to the same area.

In 1968 the United States accounted for 18 percent of total hectares treated aerially while possessing 31 percent of the worlds' aircraft whereas the Soviet Union treated 46 percent of the total area with 43 percent of the worlds' aircraft.

TABLE 1
WORLD-WIDE AIRCRAFT USE FOR PLANT SEEDING, PROTECTION, AND NUTRITION AS WELL AS VECTOR AND LOCUST CONTROL.
(Treated area is actual hectares x number of treatments) 1968

Country	Aircraft	Treated Hectares	Country	Aircraft	Treated Hectares
	(Nos.)	*(Thous.)*		*(Nos.)*	*(Thous.)*
Algeria	7	42	Israel	33	467
Angola	4	10	Italy	32	264
Argentina	450	5000	Japan	158	1622
Australia	260	6170	Madagascar	10	57
Austria	17	18	Malaysia	1	5
Bulgaria	80	160	Mexico	450	8000
Cameroon	6	30	Morocco	12	36
Canada	666	2130	Mozambique	2	8
Chile	20	127	Netherlands	18	70
China	200 (est.)	1600 (est.)	New Zealand	213	3320
Colombia	208	2563	Nicaragua	190	3834
Costa Rica	9	84	Norway	5	4
Cuba	184	5152	Pakistan	50 (est.)	41
Cyprus	1	4	Peru	170	1000
Czechoslovakia	92	665	Philippines	10	50
Denmark	14	56	Poland	50 (est.)	300
El Salvador	136	3395	Portugal	10	38
Egypt	23	81	South Africa	30	3000
Ethiopia	5	425	Spain	89	1674
Finland	7	20	Sudan	50	1300
France	50	159	Surinam	5	81
German Dem. Rep.	100	1840	Sweden	36	180
Germany, Fed. Rep. of	18	44	Syrian Arab Rep.	6	25
Greece	15	523	Taiwan		(Limited)
Guatemala	157	3432	Thailand	6	
Honduras	23	470	Turkey	55	464
Hungary	34	320	United Kingdom	47	245
India	28	405	Uruguay	70	1100
Iran	37	550	United States	5700	31800
Iraq	14	51	U.S.S.R.	8000	81000
			Yugoslavia	94	1200
				Σ 18,476	Σ 177,772

Source: Akesson, N. and Yates, W., "The Use of Aircraft in Agriculture", *Food and Agricultural Organization of the United Nations*, Rome 1974 (U.S. figures modified by IAAC 1968 data).

A more recent (1973) estimate of the world situation is presented in Table 2.

The 1973 estimate indicates a growth of 14 percent in the worlds' agricultural aircraft and a decline of 4 percent in hectares treated. The data in Tables 1 and 2, although referenced from different sources, are based upon data supplied by the International Agricultural Aviation Center of The Hague, Netherlands.

Assuming that the Table 2 European data is dominated by the Soviet Union and that the American data is dominated by the United States, it is shown that the Soviet Union was treating more hectares per aircraft than the United States (1968: 10,000 hectares per aircraft to 5600 hectares per aircraft; 1973: 9,474 hectares per aircraft to 6,897 hectares per aircraft). However, in 1974, the United States treated 81 million hectares at a 10,125 hectares per aircraft rate, an apparent "closing of the gap."

Table 5 illustrates the dramatic decrease in accident rates and fatal accident rates for ag-air during the 1965-1973 time period.

A comparison between ag-air and all of general aviation is available for certain years in Table 6. Note that in the most recent years ag-air has an equal or superior record in fatal accidents due largely to the unique construction of these aircraft.

U.S. Agricultural Aircraft Shipments

Shipments of agricultural aircraft by the major U.S. suppliers are detailed in Table 7. The shipments increased at a rate of approximately 40 percent per year through the period 1970-1973. The 1974 figures indicated an increase of 70 percent over 1973. Partial data for 1975 indicated a decrease over 1974 shipments. However, approximate cost data indicates that the final 1975 shipment value should exceed that of 1974 due to price increases.

TABLE 2
WORLD SITUATION (1973)

	No. Aircraft	Area treated Hectares (millions)	Hectares per Aircraft
Europe (incl. USSR)	9,500	90	9,474
America (North & South)	8,700	60	6,897
Asia	950	9.5	10,000
Oceania	650	8.4	12,923
Africa	300	3.5	11,667
	21,000	171.4	

Source: "Interavia", October 1973.

U.S. TRENDS

Table 3 provides insight into U.S. trends in aerial applications. The total area treated in the United States increased substantially every 10 years despite only a gradual increase in the number of aircraft used. The trends in crops treated and formulations used can also be observed in this table. In 1950, about 50 percent of the materials were applied as dusts and about 38 percent as sprays. By 1960, spray applications were ahead of dusts and by 1970, greatly reduced spray volume and ULV had replaced the more hazardous dust formulations.

Table 4 provides additional insights into the most recent 5 year period. A 19 percent increase in number of aircraft and a 14 percent increase in annual flight hours per aircraft are observed over that time period.

CURRENT AGRICULTURAL AIRCRAFT UTILITY

Agricultural aircraft perform a wide variety of agricultural and nonagricultural tasks. In addition to the obvious tasks of fertilization, seeding and pesticide application, aircraft have been used to spread fungicides on logs floating outside sawmills in the Pacific Northwest to prevent rot. They spread nitrates over Pacific Ocean oyster beds to encourage growth of plankton. Helicopters have been used to blow pecans and walnuts off trees, to dry Washington's Yakima valley cherry crop when excessive rain threatened rot, and to hover above Florida's citrus groves sending warm air down into the chill air below.

TABLE 3
TRENDS IN MATERIAL FORMS AND USES OF AIRCRAFT
APPLICATIONS, AREAS TREATED, AND NUMBERS OF AIRCRAFT

U.S.A.	1950	1960	1970
	Percentage of total treatment area (ha x no. of treatments)		
Forms:			
Spray pesticides	38	46	75 (est.)
Dust pesticides	49	39	5
Granular pesticides	—	3	8
Fertilizer	6	5.5	7
Seeds	7	6.5	5
Uses:			
Agriculture defoliant	4	3.5	5 (est.)
Insecticide	—	73.3	59
Fungicide	—	1.8	8
Herbicide	—	12.7	18
Forest (insect)	—	2.7	3
Miscellaneous	5	6	7
Total hectares treated (millions)	16.2	29	42
Total number of aircraft	4500	5130	6100

Source: Akesson, N. and Yates, W., *The Use of Aircraft in Agriculture*, Food and Agricultural Organization of the United Nations, Rome 1974 (U.S. figures modified by IAAC 1968 data).

TABLE 4
AGRICULTURAL AVIATION TRENDS IN U.S.

Year	No. of Aircraft	Miles Flown	Hours Flown	Hrs/Yr/AC
1970	5,802	134,674,676	1,395,711	241
1971	5,530	135,305,028	1,397,998	253
1972	6,338	156,608,948	1,615,687	255
1973	6,736	182,352,340	1,846,590	274
1974	6,916	189,241,771	1,892,586	274

Source: FAA Reports of Aircraft Statistical Files from Form AC8050-73.

TABLE 5
AG-AIR ACCIDENT RATES

	Total Accidents	Fatal Accidents	Total Accident Rate per 100,000 hrs flown	Fatal Accident Rate per 100,000 hrs flown
Jan 1 - Sept 14				
1975	388	28		
1974	438	29		
1973	415	51	20.54	2.38
1972	376	38	21.20	2.14
1971	394	40	28.00	2.84
1970	363	41	23.88	2.70
1969	390	35	27.31	2.45
1968	367	39	28.63	3.04
1967	404	42	35.82	3.72
1966	323	44	31.12	4.24
1965	350	38	30.62	3.32

Source: For years 1974 and 1975: NAAA, *World of Agricultural Aviation*, November 1975.
For years 1965-1973: NTSB Annual Review of Aircraft Accident Data, U.S. General Aviation.

TABLE 6
GENERAL AVIATION/AGRICULTURAL AVIATION ACCIDENT RATES*

	General Aviation (Total) per 100,000 hrs flown	General Aviation (Fatal) per 100,000 hrs flown	Agricultural Aviation (Total) per 100,000 hrs flown	Agricultural Aviation (Fatal) per 100,000 hrs flown
1964/1965	32.2	3.3	30.6	3.3
1969	18.8	2.6	27.3	2.5
1972	15.0	2.6	21.2	2.1
1973	14.1	2.4	20.5	2.4

**FAA Statistical Handbook of Aviation*, Calendar Year 1973.

The main reasons for the growth of ag-air are not in these esoteric applications, however; rather, the factors which contribute most to industry growth are:

- Mounting labor costs
- Increases in the number of treatments of each crop
- Speed of application
- Ability to make the application without physically entering the drop area

A recent Wall Street Journal article states:[4]

"Farmers who use ag airmen say one factor is that it is almost impossible to get competent help to spread pesticides by ground. One airman can cover 100 acres with herbicides in an hour—a task that often takes a ground rig all day.

"Moreover, advocates say, planes can do many things better than ground rigs. Clarence C. Williams, west Texas vegetable farmer, says, "Sometimes you need to get fungicides on right quick" at a specific time during the growing season. On a 3,000 acre rice farm, or on the huge sweet corn fields in Minnesota, there often isn't any other way to cover the area, according to growers.

"Additionally, aerial application usually causes little or no crop damage. Soil compaction, which hurts crop growth, is avoided. When crops are rotated, aerial seeding can be done even before the previous crop is harvested, allowing the seeds extra time to germinate. Planes can spread fungicides on earth too wet to support ground machines.

"New wrinkles in ag aviation are surfacing all the time. Some 90 percent of the U.S. rice crop now is seeded by air, and other small grains and grasses

[4] *Wall Street Journal*, May 7, 1973.

are increasingly planted the same way, In Minnesota, farmers are experimenting with seeding feed corn aerially. Yields have more than doubled, as there are more corn plants to an acre, but harvesting machines that can cope with row corn aren't adaptable to broadcast planting, says Terry Pfeil, President of Sky-Farmers.

"Biological pest controls also are being spread by air. Agriculture Department officials spread sterilized male screwworms across the Southwest to limit the reproduction of these cattle pests. In California, planes are used to spread pest-devouring wasps and lady-bugs in the fertile San Joaquin Valley. And control of predators by aircraft particularly coyotes in the West, is expected to soar since the government has sharply curtailed use of poisons."

Many of the areas in which aerial application presently makes a significant impact are listed below and summarized in the paragraphs that follow:

- Agriculture, seeding, fertilizing and pesticiding
- Range and forest management
- Wide area pest control (U.S.)
- Wide area pest control (Foreign)
- Developing nations agricultural support

TABLE 7
SHIPMENTS OF AGRICULTURAL AIRCRAFT 1970-1975*

Manufacturer	No. of Units					
	1970	1971	1972	1973	1974	1975
Grumman American Aviation Corp.						
Ag Cat G-164A		103	142	175	185	192
Piper Aircraft Corp.						
PA 25-235 Pawnee D	71	82	32	32	210	124
PA 25-260 Pawnee	67	45	31	10	118	37
PA 36-285 Pawnee Brave				62	40	163
General Aviation Division, Rockwell International Corp.						
Thrush Commander 600	47	52	99	162	253	65
Thrush Commander 800						34
Cessna Aircraft Co.						
Ag Carryall A185F			8	8	17	28
Ag Pickup 188B			22	15	7	9
Ag Wagon A188B	118	140	182	169	155	71
Ag Truck A188B			42	157	350	363
Totals	303	422	558	790	1335	1086

*1975 totals are through November.

Source: General Aviation Manufacturers Association.

Agricultural Seeding, Fertilizing and Pesticiding[5]

The following comments by Mr. Dean Noble summarize the impact of ag-air on agricultural seeding, fertilizing and pesticiding.

"Any discussion of the services provided by agricultural aviation would not be complete without first looking at the world agricultural markets. These markets have undergone dramatic change in the past two years. For example, food and fiber prices have skyrocketed. The exporting countries, including the United States, have moved from surpluses to shortages, from heavy promotion of agricultural products to controlling them. Acreage and production controls which have become a way of life for four full decades, have been stripped away and farmers have been asked to go all-out for food production, something that has never happened before during a peacetime period

"The record shows that aerial application services have been growing the past three years at an annual rate of 20 percent. However, even with this growth, in the international area today there are an estimated 3.5 billion acres in cultivation of which only one to two percent are receiving these services.

"The United States, which is acknowledged to be the most advanced in utilization of ag-air, has approximately 350 million tillable acres. It is estimated that only 15 percent of this acreage is receiving aerial application service.

"Looking at individual crops, 90 percent of the rice grown in the United States is seeded, and insects and weeds are controlled, all by air. Seeding wheat by air is receiving better acceptance every year. The crop is also protected from disease and insects through aerial application. Cotton is heavily dependent upon the services of ag-air, especially in the area of insect control. As recently as three years ago, soybeans, a very important export in the United States, did not benefit from aerial application services. Today, we have received reports of up to seven applications to a crop. Most of this growth in utilization on soybeans can be attributed to applying herbicides for weed control, and desiccants for drying the crop. Desiccant application alone has provided growers of soybeans with gains of 2.5 to 6 bushels an acre. It has also allowed the beans to be combined up to 60 percent faster.

"These examples clearly indicate the contribution that ag-air is making, and will continue to make, to help solve the world's food and fiber supply problems."

Range and Forest Management[6]

Forests occupy about 732 million acres of land in the United States; 530 million acres are classified as commercial forest lands leaving about 200 million acres in parks, wilderness areas and other withdrawn areas. Range and pasture lands occupy another 640 million acres. Such areas need protection against fire, disease, insects, erosion and undesired vegetation.

The opportunity for aerial application to control weeds and brush on our ranges is extensive. Survey studies have shown that there are about 80 million acres of land infested with sagebrush and some rabbit brush. Fields of forage have increased two to five times for two to three years after aerial treatment with 2, 4-D in these areas.

In California, Arizona and Western Oregon, chaparral on 20 million acres of land reduces forage and available soil moisture and greatly increases fire hazard compared to grass cover. Properly timed sprays of 2, 4-D and 2, 4, 5-T can be used with other measures to regain the benefits from these resources.

There are several million acres of prickly pear cactus in the Western States that compete directly with grass forage and also repel livestock and render large areas unusable. In addition to the 58 million acres of mesquite in Texas, there are 6 million acres in Arizona and New Mexico. Treatment with low doses of 2, 4, 5-T or silvex will greatly increase grazing potential.

In forestry, thousands of acres of established conifers in Western Oregon and Washington are treated aerially with 2, 4, 5-T in diesel oil during dormancy to remove competing hardwood brush. This herbicide alone or with 2, 4-D is applied to many thousands more acres during the very early or late summer growing season to control brush in other conifer forests.

It has been demonstrated[7] here in the United States and in Australia and New Zealand that aircraft can be used to improve grazing areas by means of weed and pest control.

[5] Noble, D., "Ag Aviation and the World's Food Crisis"; *World of Agricultural Aviation*, Cessna Aircraft Co., June 1975.

[6] "Herbicides in Range and Forest Management," *Aerial Applicator*, June 1974.

[7] Maan, Dr. W. J., "World Trends in Agricultural and Forestry Aviation," *World of Agricultural Aviation*, May 1975.

World demand for timber has led forest management people to press for even greater production per acre. Aerial application of fertilizer is playing an increasingly important role in this production.[8] In 1972, the Weyerhauser Corp. treated 150,000 acres and almost doubled that amount in 1973.

Wide Area Pest Control (U.S.)

The Plant Pest Control Division, Agricultural Research Service of the U.S. Department of Agriculture, contracts for aerial application of 20-30 million acres annually through Federal and state cooperation programs. Additionally, several states prefer to issue contracts individually. Typical pests protected against include the grasshopper, imported fire ant, gypsy moth, pink bollworm and pine butterfly.

Tussock Moth. Helicopters, like the Bell 205A-1, have recently been engaged in controlling the Tussock Moth.

> "In 1973 its insatiable appetite accounted for the destruction of 800,000 acres of timber in the Pacific Northwest.
>
> "To give an idea of the severe and sudden damage caused by the invaders (each larva consumes up to seven needles a day), a swarm can demolish a 120-year-old Douglas fir in matter of days.
>
> "Not only have the tiny Tussocks been an added threat to our current energy crisis but the tab for lumber loss and rehabilitation will run into a multi-million dollar figure.
>
> "As the situation reached a critical high, however the U.S. Forest Service received special permission from the Environmental Protection Agency to launch a DDT attack.
>
> "Simultaneous spraying began in early June in Washington, Idaho and Oregon in an attempt to prevent an impending tree attack on 460,000 acres of federal, state, private and Indian reservation lands.
>
> "The principal contractor, Evergreen Helicopters, Inc. of McMinnville, Oregon, was assigned to spray 375,000 acres in the three states. From Evergreen's 'moth fighting' squadron of eight helicopters, the major spraying assignments were given to five Bell 205 'Hueys' and a Bell 206B Jet Ranger.
>
> "Evergreen reported that the results had proven to be 100 percent successful. The march of the moth had been stopped by the helicopter."[9]

Grasshopper. The recent grasshopper infestation in Washington and Idaho required aircraft larger than the popular agricultural aircraft. Statistics supplied by a USDA Supervisor for Washington and Oregon indicate that the potential damage which was averted would have been spectacular.

> "On sparse grassland four grasshoppers per square yard cause a 62% reduction in forage per summer. In Washington alone, over a million acres were affected by infestations running as high in some areas as 75+ hoppers per square yard. In Washington, costs ran at 55 to 60 cents per acre and were split equally three ways among ranchers, the state, and the federal government. So, we're talking about a single agricultural spray operation with costs in excess of half a million dollars.
>
> "The Washington job was borken into four segments: roughly 216,000 acres handled by Aero-Dyne Corp., Renton, Wash.; two blocks of roughly 55,000 acres and 108,000 acres sprayed by Transmountain, Omak, Wash.; and 700,000 acres covered by Christler Flying Service, Thermopolis, Wyo. In all four cases Malathion (American Cyanamide 95% technical) was applied at the rate of eight oz. per acre.
>
> "The situation in Idaho was a bit more complex. About 800 thousand acres of spray work were broken up onto eight segments and bidding, due to wide variations in terrain and loads that could be carried, ranged all the way from $1.60 to (in one case) $4.00 per gallon.
>
> "Aero-Dyne handled a 436 thousand acre job, Christler a 78,400 acre job, and Reeder Flying Service, Inc., Twin Falls, handled several blocks totaling about 96 thousand acres. Clayton Curtis, Lake Placid, Fla. took on 111.5 thousand acres.
>
> "Handling these large acreages required ships larger than the popular agricultural aircraft. Aero-Dyne sent 3 DC 3's to battle the hoppers in Washington. President Dick Delafield said that Aero-Dyne picked up the entire Hughes Air West fleet of DC 3's, eight ships.
>
> "Flying at 140 knots 80 to 100 feet above the ground, a 500 foot swath was achieved. Each flight covering 8400 acres lasted one hour. Reloading required about 15 minutes due to the fact that the

[8] "Forest Fertilization," *Aerial Applicator*, Vol. II, No. 7, August 1973.

[9] "Helicopters Wage War on Moth Invaders," *Aerial Applicator*, Vol. 12, No. 8, September 1974.

USDA was supplying the Malathion in 55 gallon drums. The best Aero-Dyne could do to get around this awkward situation was to have the ground crew prefit the drums with quick disconnects.

"Christler Flying Service, sent four ex-military 749 Constellations flying formation into the fray.

"On the job, each ship took on 2000 gallons (that's 32,000 acres worth) in a 30 minute loading operation to prepare for a three hour flight.

"The Constellations flew between 75 to 100 feet above ground level and achieved a 750 foot swath width. Flying formation the four Connies had a combined swath width of 3000 ft. Dick Jackson reported that the longest run was 55 miles from the Snake River north to Sprague. Flagging was accomplished by spotter planes, with landing lights on at start and finish of each run, combined with jeeps on available roads in between. Radio contact with an overhead observation plane was also necessary.

"Rough terrain in Idaho called for some smaller craft and higher application costs. Reeder Flying Service, Inc. used two TBM's carrying only 450 gallons. Charles Reeder said the plane can carry 700 gallons but so much maneuvering was required that, if he took on 700 gallons of spray, he would run out of fuel before he ran out of insecticide. The TBM's flew about 170 mph at an approximate 100 foot altitude achieving a 300 foot swath."[10]

Wide Area Pest Control (Foreign)[11]

The World Health Organization has initiated a 20 year, $120 million program for precision spraying of rivers by airplane and helicopter in the Volta River basin of West Africa. The aim is to rid a 400,000 square mile region, including eight nations, of a parasitic infection.

Approximately one million persons in the region are infected by a threadlike worm carried by the female blackfly. Of the infected persons, at least 70,000 have become blind because the parasite invaded the eyes.

The disease is most rampant in the fertile river valleys, and in some areas almost every person who reaches the age of 40 expects to go blind. As a result the bulk of the population has been forced to farm less fertile regions upland. United Nations' studies indicate a return equivalent to hundreds of millions of dollars if the rich valleys could be made habitable for farming.

The entire territory has been divided into areas in which streams will be sprayed successively during the planned 20 year period of the program. Considerable overlapping and repeat spraying are planned. Control of this nature has never been attempted before because of the impossibility of covering such a large area methodically from the ground.

Technical demands of the program are strict because of the need to spray with great precision. Overdumping of the larvacide would cause permanent environmental damage while too little would be ineffective. The required rate would vary from stream to stream and from season to season.

As a second potential example,[12] vast areas of Africa are afflicted with the tse-tse fly, transmitting a cattle disease which makes beef and milk production impossible. It has been proven that by aerial insecticide spraying the tse-tse fly can be killed. It is realistic to attempt to eradicate this cattle pest over a large area.

Developing Nations Agricultural Support[13]

"Ciba-Geigy, Limited, had, in the 1960's, realized the importance of application methods in determining the effectiveness of pesticides.

"The philosophy at Ciba-Geigy is to utilize improved standards of application, especially aerial application, as a form of product promotion."

"The main markets of Ciba Limited at the time this philosophy gained impetus lay in the developing parts of the world where there is a pressing need for aerial application of insecticides, due to the vast areas under irrigated cultivation, and the severity of pest outbreaks in such tropical and subtropical regions. Since local operators were frequently not available, Ciba-Geigy was compelled, under certain circumstances, to expand from demonstrations into the execution of integrated large-scale commercial application projects.

"The company carried out its first aerial application in the year 1968, when the government of Indonesia entrusted it with the treatment of three hundred thousand hectares of rice fields in Java against stemborers. During four growing seasons from 1968 to 1970, Ciba-Geigy treated, with 13

[10] "Operation Grasshopper," *Aerial Applicator*, Vol. 12, No. 1, Jan/Feb 1974.

[11] "Massive River Spraying Project Planned," *Aviation Week and Space Technology*, April 29, 1974.

[12] Maan, Dr. W. J., *op cit.*

[13] Bernet, E., Ciba-Geigy Ltd., "The Chemical Industries Contribution to Agricultural Aviation," *World of Agricultural Aviation*, October 1975.

aircraft, one million hectares on an average of four times per season. The company supplied the insecticides, fertilizers, and full support management and technical services in close cooperation with the Indonesian Government. Conventional spraying techniques were inadequate to deal with such large areas where ferry distances from airstrip to crop might be great.

"Ciba-Geigy developed and utilized incremental spraying at ultra-low volume rate under Decca Highfix track guidance. Up to 20,000 hectares were treated per day, at a mean rate of 400 hectares per hour per aircraft.

"This project demonstrated, possibly for the first time, the importance of scale as a factor in yield response to pesticide application. The number of stemborers declined considerably not only during individual cropping seasons, but also from season to season, while in the areas outside the project, where the same insecticide was applied at the same rate but by the farmers themselves, the number of moths increased during each season.

"In the following years, Ciba-Geigy carried out similar operations in East Pakistan (new Bangladesh), utilizing the Decca Main-Chain for track guidance on rice; in Iran on cotton and rice; in Pakistan on rice; in the Sudan on cotton; in Egypt on cotton; in Saudi Arabia on vector control; in Indonesia again on Sexava pests on coconut palms; in Canada on forests; in Morocco on corn, cotton, and herbicides; in Ghana on rice; in Nigeria on corn and rice; in Zaire on cotton, coffee, and sugar cane; and in the Central African Republic on cotton."

ECONOMIC BASIS OF CURRENT AGRICULTURAL AIRCRAFT UTILIZATION

This section focuses on the economic basis of the individual operator. The operations of typical agricultural aircraft operators are described with an emphasis on investigating the financial viability of the industry. The financial health and structure of the industry will determine, in part, the rate of adaptation and therefore the utility of new innovations.

Costs of Operating an Aircraft

Akesson and Yates[14] provide some insight into the fixed and hourly operating costs of three different classes of aircraft. Tables 8 through 10 provide a breakdown of these costs. It should be noted that these data are aircraft associated costs only and do not reflect the additional investment and operational costs of ground-based equipment and personnel for flagging and for chemical loading and handling.

The depreciation shown under fixed costs in Tables 8 through 10 is based on an initial cost-less-salvage value divided over a 10-year period of expected life. If the aircraft is not a total loss by the end of 10 years, it must usually be completely rebuilt. Interest charges on the average value of the aircraft over its lifetime are based on cost-less-salvage value divided by two, plus salvage value times 10 percent. The taxes and hangar charges are also based on this average value of the aircraft. The last item of fixed costs is insurance, which includes coverage for various ground or storage hazards, collision or crash damage to aircraft, liability for damage to persons or to the property of others, and liability for chemical damage to crops, humans, and animals as a result of aerial drift or direct misapplication. The three cost classes of aircraft represent a variety of fixed and rotary-wing types. No helicopters of practical size and utility are available below $25,000; hence, all helicopters would fall in classes A and B.

The variable operating costs per hour include petroleum costs, costs of repairs and general maintenance, and the costs of required inspections by approved and licensed mechanics. Major engine overhaul is based on 1,000 hours of use at a cost of $5,000 (class A aircraft) to $3,000 (class C aircraft), depending on engine size. The costs for a major overhaul of radial engines are about 30 percent greater than for a comparable in-line or flat type engine, and thus raise the hourly cost where radial engines are used, as on the Grumman Ag Cat and the Aero Commander Thrush. The pilot allowance is figured at $15 per hour, but a share in the net proceeds or yearly income is frequently allowed the pilot as well.

Total costs per hour as shown in Tables 8 through 10 are the sum of the fixed yearly costs divided by the total hours of use plus the hourly operating costs. These are shown for each of the three cost classes. The fixed charges are seen to be highly dependent on the seasonal or yearly hours of use. A low use factor of 150 hours per year shows a fixed cost of $122.35 per hour for the class A aircraft. But if the hours of use can be raised to about eight times this amount, or 1200 hours per year, costs go down proportionately to about $15.29 per hour. Also, the significant difference in the fixed costs in relation to aircraft cost class should be noted.

[14] Akesson, N. B. and Yates, W. B., *The Use of Aircraft in Agriculture*, Food and Agriculture Organization of the United Nations, Rome, 1974.

TABLE 8
OPERATING COSTS FOR CLASS A ($70,000)
AGRICULTURAL AIRCRAFT

Fixed Cost Per Year

Depreciation	$ 6,300
Interest	3,850
Taxes and license	2,310
Hangar and airstrip	1,155
Insurance	4,738
Total Costs	$18,353

Variable Cost Per Hour

Fuel and oil (petrol 60¢/gal)	$ 12
Repairs, inspection per 1000 hours	18
Major engine overhaul per 1000 hours	5
Pilot allowance*	15
Total Costs	$ 50

TOTAL COST PER HOUR FOR SPECIFIED HOURS OF USE

Hrs/Yr	Fixed Cost/Hr	Variable Costs/Hr	Total Cost/Hr
150	122.35	50	172.35
300	61.18	50	111.18
600	30.59	50	80.59
1200	15.29	50	65.29

*Share in net proceeds is frequently allowed pilot as well

Source: N. B. Akesson and W. E. Yates, *The Use of Aircraft in Agriculture*, FAO, United Nations, Rome, 1974.

TABLE 9
OPERATING COSTS FOR CLASS B ($35,000)
AGRICULTURAL AIRCRAFT

Fixed Cost Per Year

Depreciation	$ 3,150
Interest	1,925
Taxes and license	1,155
Hanger and airstrip	578
Insurance	3,295
Total Costs	$10,103

Variable Cost Per Hour

Fuel and oil (petrol 60¢/gal)	$ 9
Repairs, inspection per 1000 hours	16
Major engine overhaul per 1000 hours	4
Pilot allowance*	15
Total Costs	$ 44

TOTAL COST PER HOUR FOR SPECIFIED HOURS OF USE

Hrs/Yr	Fixed Cost/Hr	Variable Costs/Hr	Total Cost/Hr
150	67.35	44	111.35
300	33.68	44	77.68
600	16.84	44	60.84
1200	8.42	44	52.42

*Share in net proceeds is frequently allowed pilot as well.

Source: N. B. Akesson and W. E. Yates, *The Use of Aircraft in Agriculture*, FAO, United Nations, Rome, 1974.

TABLE 10
OPERATING COSTS FOR CLASS C ($20,000)
AGRICULTURAL AIRCRAFT

Fixed Cost Per Year

Depreciation	$ 1,800
Interest	1,100
Taxes and license	660
Hanger and airstrip	330
Insurance	2,675
Total Costs	$ 6,565

Variable Cost Per Hour

Fuel and oil (petrol 60¢/gal)	6
Repairs, inspection per 1000 hours	14
Major engine overhaul per 1000 hours	3
Pilot allowance*	15
Total Costs	$ 38

TOTAL COST PER HOUR FOR SPECIFIED HOURS OF USE

Hrs/Yr	Fixed Cost/Hr	Variable Costs/Hr	Total Costs/Hr
150	43.77	38	81.77
300	21.88	38	59.83
600	10.94	38	48.94
1200	5.47	38	43.47

*Share in net proceeds is frequently allowed pilot as well.

Source: N. B. Akesson and W. E. Yates, *The Use of Aircraft in Agriculture*, FAO, United Nations, Rome, 1974.

When the hourly fixed costs are added to the variable or operating costs, the total hourly cost is found. Since the variable costs are the same per hour, the total cost basically reflects the differences in the fixed costs for each cost class of aircraft as well as for the hours of use per year. For example, the difference in total cost per hour between class C and A aircraft is a little over double at 150 hours of use per year, but drops to only a little more than a 50 percent increase when each is used for 1200 hours per year. Thus, the essential need for high use is most clearly shown for high-investment aircraft.

Cost of Operating An Aerial Application Service

The data presented in Tables 8 through 10 are aircraft specific and do not address the costs of equipment and personnel specific to aerial application of fertilizers and chemicals, i.e.,

- Storage facilities
- Trucking equipment
- Loading equipment
- Safety equipment
- Dispersal equipment
- Cleaning and maintenance equipment
- Disposal equipment

Depending upon the locale, the loading operation takes place at the home base of the operator or at a field convenient to the spraying operation. The operators home base is, in general, not a commercial airfield but rather a field primarily dedicated to the aerial application operation. Thus, the hanger and airstrip costs specified in Tables 8 through 10 are considered quite low for a normal ag-air operation. For example, data in the tables indicate hangar and airstrip costs of $578 for class B and $330 for class C aircraft. It would be difficult to get an annual tie-down at a commercial airfield for that price.

Hard data on individual operator costs have not been obtained at this point in the study. Based upon visits to three different, medium sized operations (3-5 aircraft), it is estimated that annual fixed costs for dedicated hangar and airstrip and for application related equipment and facilities are about the same as fixed aircraft operation costs; and that flat hourly variable costs relating to application (loaders, flagmen, expendables) are approximately 20 percent of aircraft operating costs. Additional data are being sought in this area.

Illustrative Operator Profile

Personal interviews and inspections of a typical Florida operation with three class B aircraft, yielded the following replacement cost estimates.[15]

Aircraft and dispersal equipment	$120,000
Airstrip, hanger and maintenance facilities	90,000
Chemical loading equipment	40,000
TOTAL	$250,000

Observation and discussion of spraying operations indicated the following:

Acres/hour/aircraft	40-80
Revenue/acre	$1.50-$2.50
Hours/year/aircraft	600
Approximate gross revenues	$210,000

From data in previous paragraphs, it is possible to estimate an operator's return on investment. Of the $210,000 approximate gross revenues, expenses amounted to about $156,000, leaving a net profit of $54,000. Subtracting the operator's salary of approximately $20,000 yields a corporate profit of $34,000. Dividing the net profit by the net investment of $250,000 gives a return on investment of approximately 14 percent.

Investment Criteria

The implementation of technological innovation depends, in part, on the financial viability of the industry, that is, whether the innovation could increase efficiency, decrease costs, or increase the market potential. Here, note particularly (1) the effect of technological innovations on the cost structure of the industry, and (2) the ability of the industry to attract the necessary investment capital to implement potential future technological innovations.

Economic theory and empirical evidence reveal that firms should invest in a given enterprise if the expected marginal revenue of the enterprise is greater than or equal to its marginal cost and/or if the return on investment (ROI) in the given enterprise is favorable compared to that of other alternative investment opportunities. Thus, one could investigate the nature of the cost structure of this industry to determine whether technological innovations could, in fact, impact the cost structure in a healthy way. Of further interest is the return on investment in this industry compared to alternative investments.

[15] Facilities are used for a flying school as well as for the aerial application operation. Cost estimates are for replacement since equipment and facilities were built up over a period of time.

Market Forces

It has been demonstrated that this industry is presently operating on the decreasing portion of its cost curve. As output is increased, cost per unit decreases since fixed costs are therefore allocated over larger quantities of output. It follows from this that the industry should strive to increase volume. However, there are two basic limitations to the amount volume can be increased: (1) technological, and (2) demand. Further study is needed to determine the technical limitations of such variables as weather conditions and aircraft capacity. The demand constraint, however, could be quite variable, depending on price and other market forces.

For example, as flying hours increase, costs per hour to the operator decrease thereby increasing his profit. This is demonstrated by the downward movement along the cost curve C_1, in Figure 6. The supply curve S_1, on the supply and demand diagram in Figure 6 is derived from the cost curve. The operator is willing to supply more since his costs are lower; however, at current prices, only quantity Q_1, shown in Figure 6 will be purchased. At that price (Q_1), many segments of the potential market may still prefer to use conventional methods of chemical application or take their chances by not using chemicals at all. However, technological innovations would decrease production costs, causing the cost curve in Figure 6 to shift down from C_1 to C_2 which would, in turn, cause the supply curve in Figure 6 to shift to the right from S_1 to S_2. Thus the quantity of ag-air services would increase in Figure 6 from Q_1 to Q_2. This analysis is predicated on the belief of many ag-air experts that demand is elastic (i.e., a relatively small change in price would result in relatively large increase in demand). If demand were not elastic (i.e., inelastic) technological innovation might not increase demand in sufficient quantity to justify the expense. A comparison of the increased quantity demanded due to a shift in the supply curve for both elastic

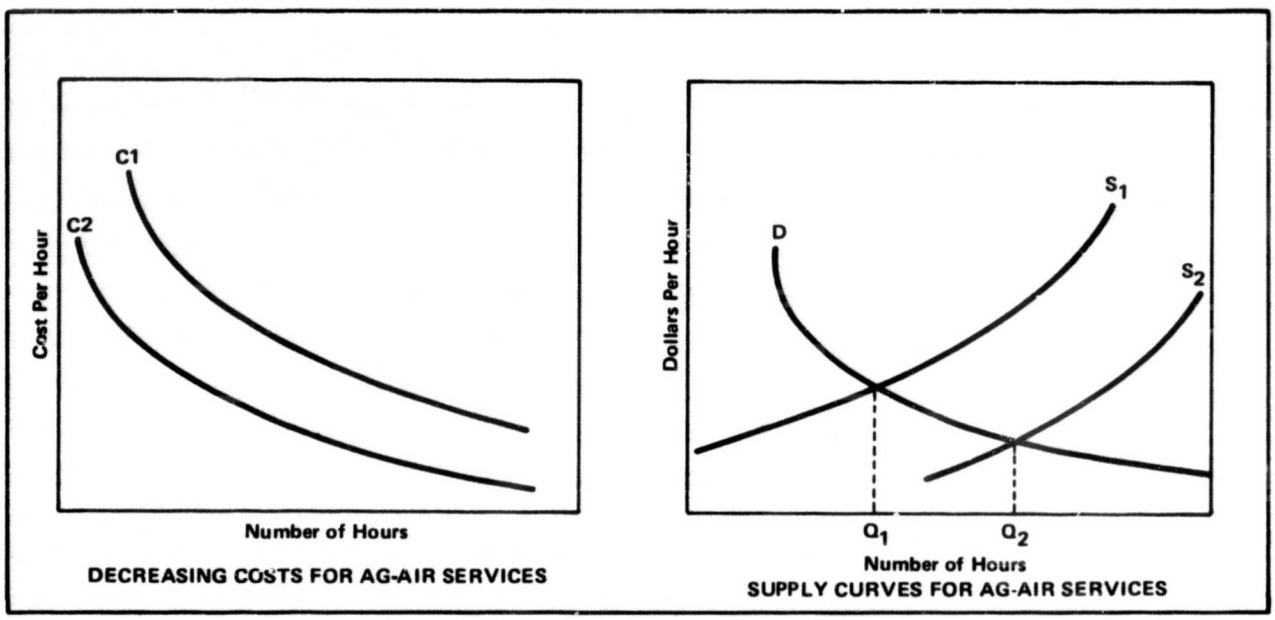


FIGURE 6. COST AND SUPPLY CURVES FOR AG-AIR SERVICES

and inelastic demand curves is displayed in Figure 7. At present there is insufficient market data to determine the elasticity of demand for ag-air services. Therefore, a first step in future research should be a study of the market potential and price elasticities. Some evidence indicates that the demand curve is "kinked." That is, it is relatively inelastic up to a point where it abruptly changes and its slope decreases sharply. Below this point, or price, demand explodes. This is illustrated in Figure 8. The explanation for this phenomenon is that at a given price, there is a psychological resistance level beyond which farmers are unwilling to spend for their services. Of further importance are the relative costs of ground applications. Further market studies are needed to substantiate this hypothesis.

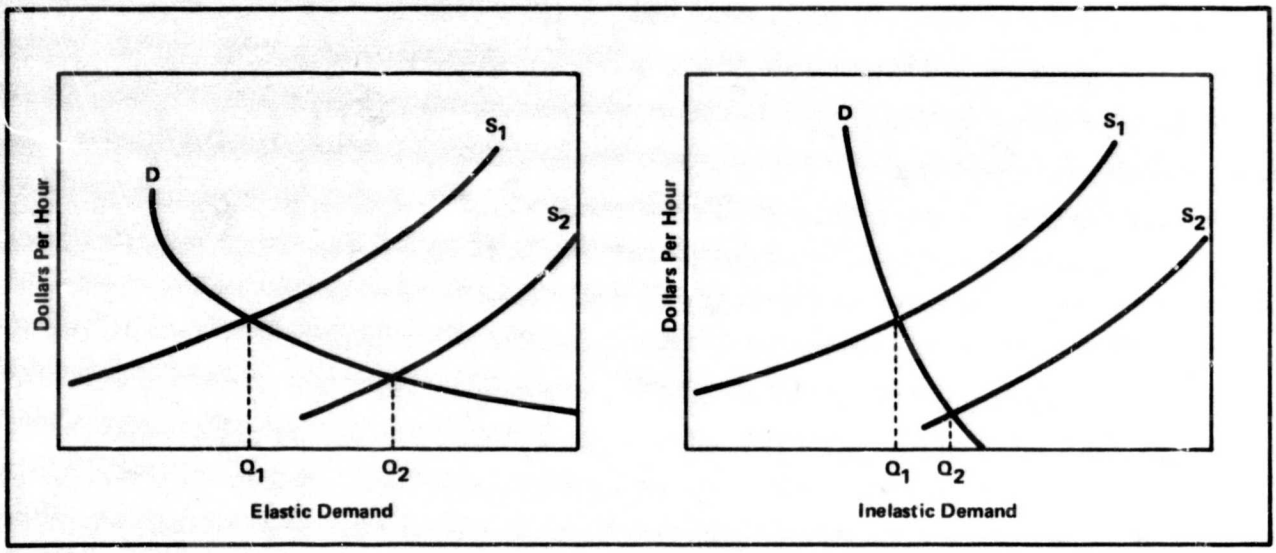


FIGURE 7. DEMAND FOR AG-AIR SERVICES AT DIFFERENT ELASTICITIES

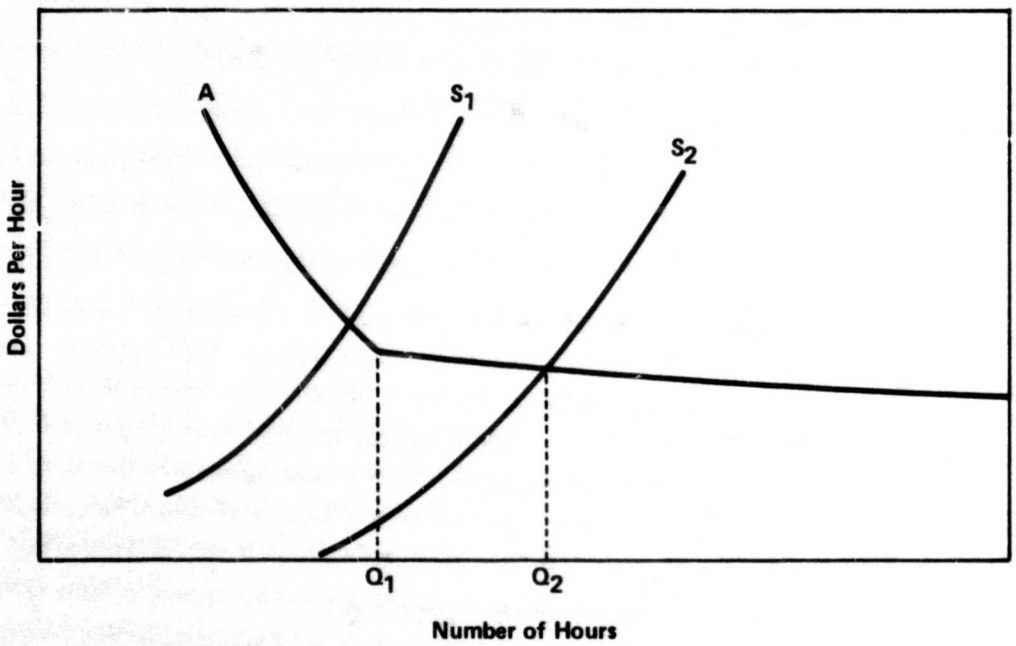


FIGURE 8. KINKED DEMAND CURVE FOR AG-AIR SERVICES

Return on Investment

The basic measure of the strength of a given industry is its return on investment (i.e., net profit ÷ investment cost). If this basic measure is low, the industry may not be in a position to sustain high levels of investment necessary for modernization. One Florida operator has a ROI of about 14 percent. Table 11 shows annual rates of profits (before taxes) on stockholders' equity for various industries in the United States for 1972. These figures range from 14.4 to 22.6 percent. However, it must be noted that: (1) some of these industries are highly leveraged by long-term debt and therfore, the return on capital is significantly lower; (2) the 14 percent figure used above for the Florida operator is return on total capital; and (3) the national figures cited in the table are dominated by large corporations, much of whose revenues do not go to investors, but to corporate income taxes, whereas ag-air operators tend to be small businessmen whose corporate income taxes are at a minimum.

TABLE 11
RATE OF RETURN ON
STOCKHOLDERS' EQUITY
FOR SELECTED U.S. INDUSTRIES
1972

Industry	Percent Rate
All manufacturing	18.4
Durable goods	19.6
Transportation equipment	23.6
Aircraft and parts	14.4
Electrical machinery & equipment	20.1
Other machinery	20.1
Non-durable goods	17.2
Food and kindred products	20.2
Chemicals & allied products	22.6

Source: Federal Trade Commission, *Quarterly Financial Report for Manufacturing Corporation, First Quarter, 1973.*

Between 1962 and 1971 the after tax rate of return on stockholders' investment for 249 identical corporations in 21 selected industries fell into the following ranges.[16]

Chemicals and allied products 12.2%-16.7%
Engines and turbines 11.1%-18.6%
Blast furnances, steel works, etc. 4.4%- 9.0%

[16] Federal Trade Commission, Quarterly Financial Reports for Manufacturing Corporations.

Based on these comparisons, an ag operator is operating a fairly profitable business and further investment in the ag-air business is likely to produce returns that are quite good compared to other industries. However, further data on other firms in the industry are needed before this brief comparison can be generalized to include the entire industry.

IMPACT OF AG-AIR ON AGRICULTURAL PRODUCTION

It was stated previously that a 10 percent increase in farm production can be attributed to ag-air. Subsequent paragraphs present data relative to increases in farm productivity and discuss some of the underlying reasons for the productivity increases that have occurred. Ag-air's contribution to increased farm productivity is understandably related to the increased use of fertilizers, pesticides and herbicides.

Agricultural Production

The primary trend in post World War II U.S. agricultural production has been a mild increase in acres under cultivation and a huge increase in the amount of food and fiber grown and in the utilization of fertilizers, pesticides, herbicides and other technological innovations. Table 12 shows the trend in crop acreage for principal crops from 1963 to 1973. During that time period planted acreage for principal crops increased from 299

TABLE 12
PLANTED ACREAGE FOR PRINCIPAL CROPS
(U.S.)

Year	Total Planted Acreage (millions)
1963	299
1964	298
1965	297
1966	293
1967	305
1968	299
1969	291
1970	293
1971	306
1972	295
1973	320

Source: Statistical Reporting Service.

million acres to 320 million acres, or about seven percent. During this same period realized gross farm income rose 127 percent from $42.7 billion to $96.9 billion. This can be observed in Table 13.

TABLE 13
GROSS FARM INCOME (U.S.)

Year	Income (billions)
1959	37.8
1960	38.4
1961	40.2
1962	41.7
1963	42.7
1964	43.1
1965	45.5
1966	50.5
1967	49.8
1968	51.7
1969	56.3
1970	58.6
1971	60.6
1972	69.9
1973	96.9

Source: Economic Research Service.

Trends in Farm Productivity

The scarcest resource used in the production of food is land. This fact, plus the rapidly increasing world demand for food, shows that increased return per hectare of land has and continues to be of permanent importance in agricultural production. Average increases in grain yields per hectare since 1950 are shown in Table 14.

The increased use of fertilizers, herbicides, insecticides and fungicides has contributed significantly to the increase in productivity. Increases in agricultural expenditures for fertilizer and lime are shown in Table 15, and the increases in quantities of commercial fertilizers consumed are shown in Table 16.

Domestic farm labor has also increased its productivity at a rapid rate in recent years. This is shown in Table 17 which indicates the trend in the number of persons supplied per farmworker in the U.S. In 1959 it took 7.3 million farmers to feed 177.1 million Americans and about 21.9 million foreigners (at U.S. consumption levels). In 1972, 4.4 million farmers supplied all the food and agricultural fiber needs of 207.8 million Americans and an estimated 45.76 million people abroad (at U.S. consumption levels). This represents an increase of about 113 percent in output per farm worker. (The 4.4 million figure includes actual workers only, both family and hired. Total farm population in 1972, as noted earlier, stood at 8 million.)

Reasons for Post-War Growth in Farm Productivity

In order to understand the contributions of man-made chemicals to the performance of the agricultural sector it is important to first understand the reasons for the rapid changes in agricultural productivity during the last 30 years. There are three major sources of variability in yields of a crop over a period of years: (1) technological change: (2) meteorological variability; and (3) random occurrences. The primary variable of interest in this report is technological change.

TABLE 14
AVERAGE U.S. GRAIN YIELDS, 1950-1974
METRIC TONS/HECTARE

Grain	1950-74 Average	1955-59 Average	1960-64 Average	1965-69 Average	1970-74 Average
Wheat	1.16	1.49	1.70	1.85	2.11
Corn	2.47	3.05	3.92	4.93	5.31
Grain sorghum	1.22	1.77	2.68	3.32	3.39
Barley	1.50	1.59	1.82	2.26	2.27
Oats	1.22	1.39	1.57	1.81	1.80

Source: Statistical Reporting Service.

TABLE 15
U.S. EXPENDITURES FOR FERTILIZER AND LIME, 1959-1973

Year	Expenditures (billions)
1959	1.3
1960	1.3
1961	1.4
1962	1.5
1963	1.7
1964	1.9
1965	2.0
1966	2.2
1967	2.4
1968	2.4
1969	2.4
1970	2.4
1971	2.6
1972	2.7
1973	3.0

Source: Economic Research Service.

TABLE 16
U.S. FERTILIZER CONSUMPTION, 1959-1973

Year	Tons (millions)
1959	24.8
1960	25.5
1961	26.8
1962	28.7
1963	30.6
1964	31.8
1965	34.4
1966	36.9
1967	38.7
1968	38.9
1969	39.4
1970	41.1
1971	41.1
1972	43.1

Source: Statistical Reporting Service.

TABLE 17
U.S. FARMWORKERS PRODUCTIVITY SELECTED YEARS, 1959-72

Year	Persons Supplied Per Farm Worker		Total Farm Employment (millions)	Total U.S. Population, July 1 (millions)	
	At Home	Abroad	Total		
1959	21.4	3.1	24.5	7.3	177.1
1960	22.3	3.5	25.8	7.1	179.9
1962	24.7	3.9	28.6	6.7	185.8
1964	27.9	5.3	33.2	6.1	191.3
1966	33.6	6.0	39.6	5.2	196.0
1968	37.9	5.5	43.4	4.7	200.2
1970	39.9	7.2	47.1	4.5	203.8
1972	42.0	10.4	52.4	4.4	207.8

Source: Economic Research Service.

Technological Change

Technological change is considered by most analysts to be the most important source of variability in grain yields since World War II.[17] Technological changes, in this context are taken to include such factors as increased fertilizer applications, improved genetic qualities of seed, inve tment in machinery allowing more timely operations, increased pesticide and herbicide applications, improved management techniques, etc. Prior to the early 1940's, the contribution of this component of variability was relatively small. Since World War

[17] McQuigg, J. D., *Economic Impacts of Weather Variability*, University of Missouri, Department of Atmospheric Sciences, Columbia, Missouri, August 1975.

II, technological change has been a significant factor in the increased yields of major crops in the United States.

Reviewing past studies, a number of attempts to isolate the influence of the technology factors affecting grain yields were found. It is too early to calculate from these studies a specific estimate of those portions of increased yields which are due to each type of technology. Further study is needed to derive such an estimate. However, several observations in this regard are of interest.

Previous attempts to isolate the influence of the technological factor affecting grain yields follow two basic approaches. The first approach uses multiple regression analysis to try to separate out the influence of the various factors affecting yield. To do this type of analysis, it is necessary to include in the model the technological factors mentioned earlier as explicit, independent variables which affect grain yields. This approach raises problems of data availability and multicolinearity. The statistical property of multicolinearity would mean that it is difficult to separate out the relative effects of each of the factors affecting crop yield. Some previous studies use time as a proxy variable for all of the technological factors. This is based on the assumption that the utilization of technological innovation increased smoothly over time. One such study estimated that the variability in wheat yields due to weather and technology was about 82 percent.

Another approach to isolating the effects of technological variables on crop production is to estimate some of the regression coefficients by using data from experimental plots where the effects of various chemicals on yields have been studied. This experimental approach is especially useful in studying the effects of fertilizer applications.

Previous research in this field is voluminous. For this study however, a few preliminary observations are made:

- From 40 to 90 percent of the variation in grain yields can be explained by technological changes which include fertilizer use, genetic improvements, herbicide and pesticide use and management techniques.
- There are significant statistical and data problems involved in a precise determination of the proportion of yield variability attributable to each specific type of technological change. However, a very detailed analysis of existing works could produce more detailed estimates.
- The most significant technological factors are the use of fertilizers and the development of new genetic varieties.
- To a large extent, the effects of weather and technology are highly interrelated. Therefore, much of the literature that attempts to separate out these effects from each other is of only limited use here. For example, considerable moisture is needed to make use of fertilizers.
- To a large extent the effects of the various technological factors are interrelated and the combined use of all the technological advancements are greater than the use of a single one.

Contributions of Ag-Air

The contributions of ag-air to increased farm production are demonstrated by considering the results achieved among various crops treated aerially.

The U.S. rice industry is an excellent example of how aircraft can be used in all phases of production and of its impact on productivity. First, it has been determined that 90 percent of the U.S. rice crop is seeded by air. Next, both insecticides and herbicides are applied by aircraft when the rice is under flood and ground tractors are unable to work the fields. Furthermore, at certain periods during rice's growth, fertilizer must be applied This too is done primarily by air. With maximum utilization of aircraft, the cultivation of an acre of rice costs the U.S. grower about eight working hours, from sowing to harvest, while in certain Far Eastern countries traditional techniques require some 1000 working hours to perform the same tasks. In addition, the average crop yield is three times larger in the United States.

Earlier in this report (Chapter III), it was pointed out that as recently as three years ago, soybeans, a very important U.S. export, were not benefiting from aerial application services. Today, there are reports of up to seven applications to a crop. Much of this growth in aircraft utilization on soybeans can be attributed to applying herbicides for weed control and desiccants for drying the crop. Desiccant applications alone have provided growers of soybeans with gains of 2.5 to 6 bushels an acre and have allowed the beans to be combined up to 60 percent faster.

Three years ago, Dr. Walter Walla, extension plant pathologist from the Texas Cooperative Extension Service, Texas A & M University, initiated research on treatments of soybeans with folior fungicides. "Benlate" benomyl fungicides were tested in an effort to control soybean pod and stem blight. Although there were no noticeable differences in the beans during the growing season, when the plants defoliated, treated soybeans held their leaves longer than untreated ones and plants were brighter in color where treatment had been applied. He also realized a yield increase that averaged

eight bushels per acre as well as increased germination from beans harvested form treated plants.

The significant feature of this treatment is the fact that the fungicide applications are made at a time when the plants are too large to take most ground equipment into the field, therefore making aerial application a necessity.

Walla's findings prompted researchers in other states to undertake similar studies. Research data from investigators across the southern soybean producing areas indicate an average yield increase of approximately five bushels per acre; however, reports of substantially higher yield increases are not uncommon. Since the average soybean yield in the United States in 1973 was 28 bushels per acre, an average increase of 5 bushels per acre would increase the average yield per acre 18 percent. Again, since the fungicides must be applied by air, these significant increases in productivity could not be attained without ag-air.

Early weed control has increased wheat yields by 10 to 20 bushels per acre in the Pacific Northwest. Aerial application of herbicides in the fall and winter has enabled wheat growers to control weeds before they begin to compete with their crops for moisture and soil nutrients. Wheat spraying in the Pacific Northwest had previously been scheduled in the spring, after the cold weather had gone and the weeds were 10 to 20 inches high. Don Schumaker of Schumaker Ag-Air, was one of the first pilots to test the herbicide known as Kurnex. The first year of commercial use, he applied it in late November on a 50 acre field in the Tummony district of Idaho. The field was under observation all winter and spring since it was one of the first field trials for the new herbicide. The results included extra bushels at harvest and a field which was essentially clean of weeds throughout the spring. Last year, at least 100,000 acres of winter wheat were treated by aerial applicators in the mid-October to mid-March period. More acres are expected to receive the early application in future seasons.

In addition to fighting destructive weeds with herbicides, it has now been determined that it is cheaper to search for some kinds of weeds from the air rather than from the ground.

A case in point is the "dudiom melon," considered one of the worst weeds in California. Dudiom melon is an annual, inedible variety of cantelope with a potential to cause severe economic loss to cotton, sugar beet, alfalfa and asparagus fields. In asparagus, dudiom melon plants quickly grow to the tops of the 6 to 8 foot high ferns and spread to a 30 to 35 foot diameter. The weed smothers the asparagus, decreasing yield by 60 percent with a reported loss to growers of up to $3 million annually. Its infestation in crops, especially asparagus, is difficult to detect from the ground because of limited visibility in high growing crops and the uncomfortable summer ground conditions in the California Imperial Valley. For example, in one 80 acre field, aircraft photos revealed a probable dudiom melon infestation that had not been detected after 100 man hours of ground survey of that field.

The Department of Food and Agriculture estimated that a ground inspection survey of 4,000 acres of asparagus, with the same level of detail as that provided by aerial photography, would cost $60,000. Actual costs for a 4,000 acre aerial survey were $1,860 for the use of the aircraft and $650 for film and film processing. Such savings demonstrate the efficiency with which aircraft can be used for various agricultural purposes.

The majority of agricultural aircraft are used in the application of pesticides. One example of the importance of the application of pesticides by air is demonstrated by their use in protecting the dry pea crop. Farmers in Washington and Idaho, who produce 95 percent of the dry pea crop in the United States, have received permission from the EPA to use DDT because there is no registered compound that will control the pealeaf weevil. Virtually all DDT used on the crop will be applied by air. According to Harold Blaim, Administrator of the Washington and Idaho Dry Pea and Lentil Commission, the reason for utilizing aircraft for treatment is that timing is of critical importance. (The pealeaf weevil can destroy large areas in just a few hours.) In addition, damage from the pealeaf weevil is most severe when plants have just emerged from the ground, an event which coincides with the area's rainy seasion. In many instances, it would be impossible to enter wet fields with ground equipment. The ag-air aircraft, therefore, provides a badly needed alternative for protecting this crop.

There are numerous other cases which demonstrate ag-air's contribution to farm productivity, but those cited establish the fact that ag-air's contribution is significant.

AERIAL VERSUS GROUND APPLICATION

The nature of the crop being treated, the terrain and existing ground conditions, and the required timeliness of treatment are examples of factors which make aerial application a more advantageous method of treatment than ground application. These and other factors are discussed in the following comparison of aerial and ground application methods.

- Rapid coverage is critical when combating widespread and fast developing epidemics

when such epidemics strike major crops. Since an aircraft can cover as much area in one hour as a tractor covers in one day, aerial application is a far more suitable method for combating epidemics.

- Insects, fungus disease and unwanted weeds tend to thrive and cause the most damage in wet weather when crops are lush. By the time the fields are sufficiently dry to permit entry of ground equipment, the damage is done. Aircraft are not inhibited by wet ground and can therefore apply chemicals immediately following rain or irrigation when the fields are too wet for ground equipment.
- It is possible for ground application equipment to turn a minor infestation into a major one by picking up and spreading infestations from field to field. Aircraft are obviously not prone to this problem.
- Many crops have optimum planting dates, deviation from which will reduce yield. In addition, there is a definite schedule and right time to apply insecticides, herbicides and fungicides for attaining maximum yield. The speed of aerial application and its ability to perform, when poor conditions such as wet fields exist, permit optimum schedules to be met with less difficulty.
- Ground application can promote soil compaction. The weight of tractors, trucks and special application equipment, in addition to the heavy chemicals which they carry, is the chief cause of soil compaction. Compaction is recognized as a major problem in agriculture. Colorado State University demonstrated that forage production dropped from 5.63 tons per acre on noncompacted soil to 4.29 tons on compacted plots. Soils on which cotton is grown are particularly prone to compaction with decreased yields resulting. Farmers on the plains must conserve water and are aware of the improved drought resistance of crops grown in noncompacted soil. Quite obviously, aerial application methods do not contribute to soil compaction problems.
- Much land, especially rangeland, is inaccessible or impractical for the use of ground equipment. Rocky and hilly terrain and vast tracts of land and forests lend themselves to treatment by air rather than ground.
- It is virtually impossible for crops to receive treatments by ground equipment without suffering some damage. Drilled or broadcast crops are run down and even-row crops are in some ways damaged. Certain crops such as corn and cotton require frequent treatment after becoming quite tall. Damage is unavoidable when treating such crops by ground. Aerial application eliminates equipment that causes physical damage to crops.

IMPACT OF NO-TILL FARMING ON AG-AIR

One of the more significant future projections regarding agricultural techniques is the projected growth of no-till and minimum-till farming methods.

No-till farming is a tillage method in which crops are planted, without prior plowing or seedbed preparation, in a sod or in the residue of a preceding crop. Minimum-till farming refers to a method which employs reduced soil preparation procedures. In both methods, chemical weed control replaces post-planting cultivations. The adoption of no-till and minimum-till methods is due primarily to the introduction of new herbicides which eliminate or reduce the requirements for conventional preplanting weed control.

The Office of Planning and Evaluation, U.S. Department of Agriculture, has published a report entitled "Minimum Tillage: A Preliminary Technology Assessment," which discusses a number of significant points concerning no-till and minimum-till farming. Several of these points are presented below.

- Domestic and world market conditions currently support expansion in farm production. If this situation continues, farmers will be more inclined to take advantage of opportunities for double or multiple cropping, opportunities which are enhanced by minimum- or no-till methods. (Note: Double cropping, as the words imply, refers to a procedure whereby two crops are raised and harvested from the same field within a single growing period.] One technique in double cropping is to sow the second crop before the first crop is harvested, thus allowing final maturation of the first crop and germination of the second to occur simultaneously.
- No-till and minimum-till farming may increase land acreage cropped by making crop production feasible on lands that are subject to severe erosion damage when tilled by conventional methods.
- No-till and minimum till farming methods reduce farm machinery and labor costs. Estimates of preharvest labor savings for minimum-till methods were 58 percent for cotton and soy-

beans and 52 percent for corn and sorghum.

- According to the Soil Conservation Service, the annual rate of soil loss through erosion of farmlands in 1968 was 4 billion tons or the equivalent of about 12 tons per cropped acre. Minimum- and no-till methods have the potential of decreasing this soil loss by 50 percent or more by the year 2000.

The projected growth in no-till farming is depicted in Figure 9. The S-shaped growth curves are consistent with the adaptation rates of many new technologies, which first increase at an increasing rate and then increase at a diminishing rate until a maximum level is attained. Although less than two percent of all planted

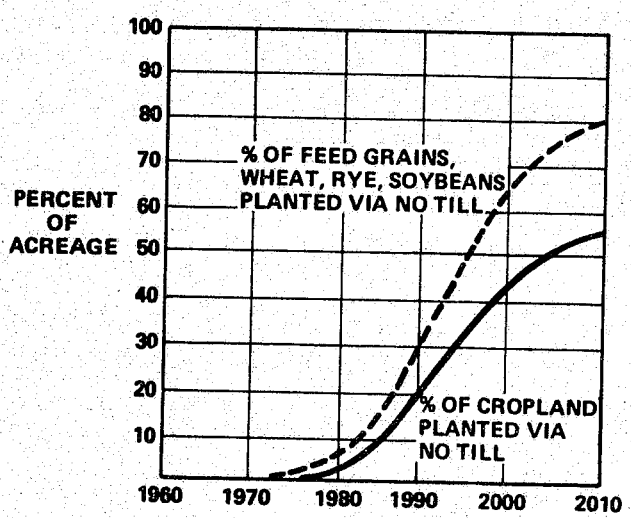


FIGURE 9. GROWTH IN NO-TILL FARMING

cropland is presently farmed by no-till methods, this figure may increase to approximately 45 percent by the year 2000. Expressed in acres, the 45 percent figure would represent 153 million acres of cropland.

Implications for Ag-Air

The effectiveness of the no-till farming system depends largely upon the substitution of chemicals for conventional cultivation in controlling weeds and pests. Therefore, the quantity of pesticides used increases as minimum- or no-till methods replace conventional tillage systems. Most no-till systems require a minimum of one application of two or more chemicals. A second application could be needed if a special weed or pest problem persists. The use of contact herbicide before and/or at the time of planting and a residual type herbicide at or soon after planting is recommended for most no-till crops.

Insect, rodent and disease problems could intensify as a result of long periods without moldboard plowing and the accumulation of surface litter (plant residue) from reduced tillage. This increased vulnerability of crops to pests could result in increased applications of pesticides.

It is reasonable to assume a minimum overall increase in chemical applications of two pounds per acre (one pound insecticide and one pound herbicide) for the 153 million acres projected for no-till methods by the year 2000.

This tremendous increase in pesticide usage resulting from the increased adoption of no-till farming techniques will have a significant impact on the ag-air industry. Presently, 60 percent of all pesticides are applied by air. If the increased pesticide usage from no-till farming is applied in the same proportion as it is presently applied, approximately 184 million additional pounds of pesticide will be applied by air in the year 2000. Aerial application of pesticides, however, will probably be higher than this figure because many of the major crops which will benefit from no-till farming methods in the future are presently receiving increasing quantities of pesticides by air even while tilled by conventional methods. For example, soybeans, which are receptive to no-till farming, are receiving increasing aerial application of pesticides to control anthracnose. These applications are being made at a time when the plants are too large to take most ground equipment into the field, making aerial application a necessity.

In summary, while the exact amount of increase cannot be accurately projected, it is clear that no-till farming methods will place a heavy demand on ag-air.

IV. PROBLEMS ASSOCIATED WITH AG-AIR

A number of problems associated with ag-air are depicted in Figure 10. Many of the problems are interrelated. In the following discussion, however, they are grouped under four general categories:

- Aircraft design and performance characteristics
- Dispersal system and flow field characteristics
- Operating constraints
- Safety of personnel

AIRCRAFT DESIGN AND PERFORMANCE CHARACTERISTICS

There is a general consensus among industry representatives that a need exists for R&T efforts to improve agricultural aircraft design and performance characteristics. It is also felt that such an effort should adopt a total systems approach wherein the aircraft and the application equipment would be considered as a single system. The R&T efforts would take a fresh look at the overall systems problem and generate design concepts, mission analyses, mission requirements, and possibly a paper design of a new aircraft and its associated application equipment.[1]

The extent of the agricultural aircraft design and performance characteristics problem can be illustrated by considering some desirable characteristics of an agricultural aircraft. The characteristics listed in Table 18 were drawn from comments by industry representatives at the Ag-Air Workshop in December 1975; from on-site meetings with aircraft manufacturers and ag-air operators; and from the book, *The Use of Aircraft in Agriculture*, by N. B. Akesson and W. B. Yates.

TABLE 18
DESIRABLE AG-AIRCRAFT CHARACTERISTICS

Low empty weight
High useful load capability
High-speed cruise capability
Low-speed delivery capability
High turn rate and narrow turning radius
High lift/low drag wing
Low profile drag (airframe and application package)
Low stall speeds
Short take-off capability
High engine and propellor efficiency
Low energy costs per flight hour
Clean combustion engine
Accurate low-level navigation equipment
Rugged, lightweight airframe construction
High survivability potential (pilot and airframe)
Low maintenance man-hours per flight hour
Rugged landing gear permitting operations from rough fields
Environmentally controlled cockpit
Corrosion resistant materials
Safe and efficient chemical loading, carrying and dispersal systems
Airfoil aerodynamic qualities optimizing wing-tip vortex impact on chemical dispersal patterns

Agricultural aircraft design and performance characteristics problems lie in determining which and to what

[1] NASA/NAAA Ag-Air Workshop, December 10, 1975.

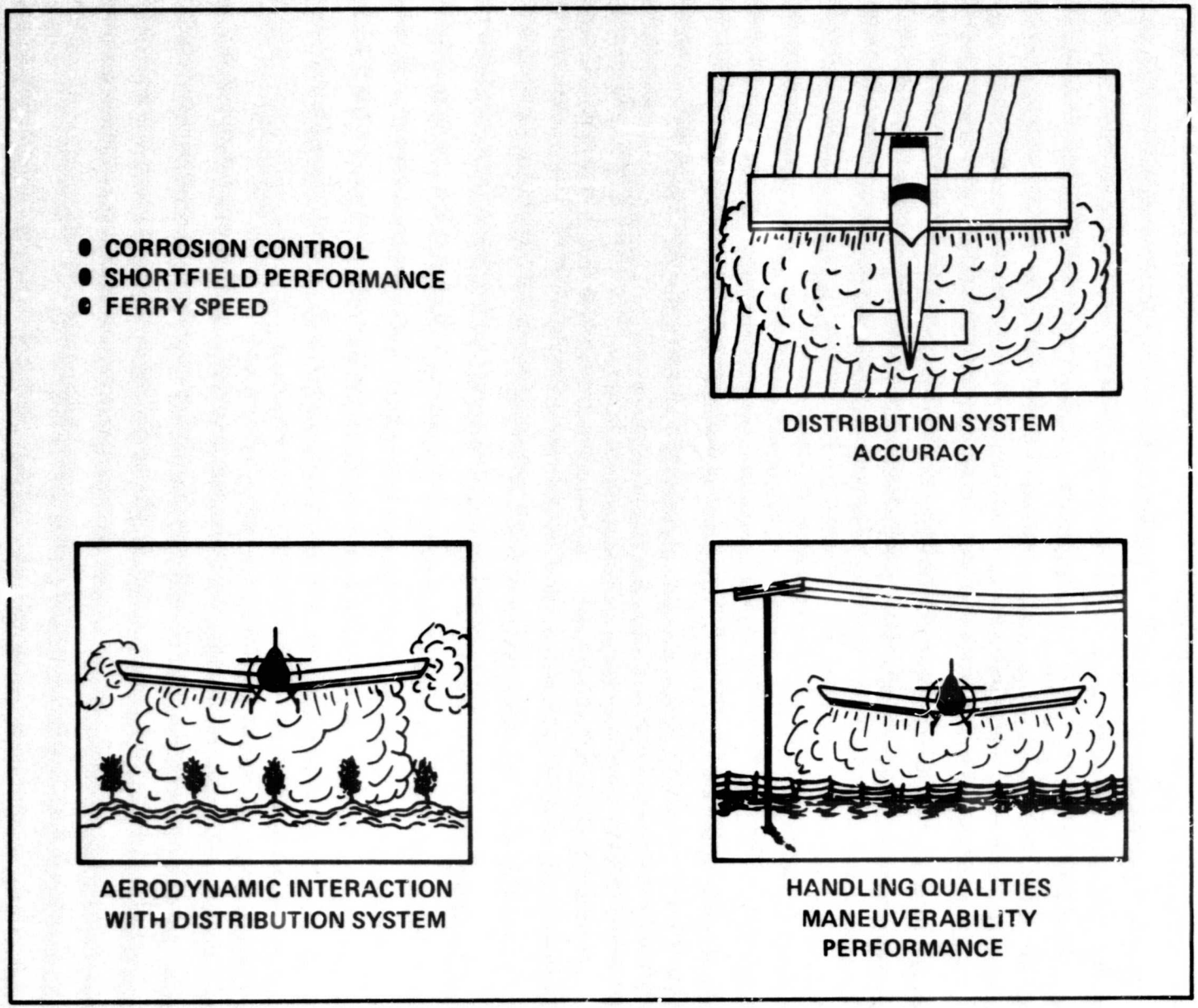


FIGURE 10. PROBLEMS IN AGRICULTURAL AVIATION

extent various characteristics will be incorporated in a single aircraft design. Incompatibilities among characteristics require analyses to determine cost-effective trade-offs. Safety considerations may take priority over design and performance characteristics. For example, rugged but lightweight airframe construction may not satisfy pilot survivability requirements. It may be necessary to add heavier structural members which would add to the aircraft's empty weight and reduce the useful payload capability. A high-speed cruise capability and a low-speed delivery capability may require a larger and heavier engine, further reducing payload capability. A larger engine may also place too great a demand on energy resources. These and other conflicts require continuing R&T efforts.

Agricultural aircraft in use today incorporate a number of the design and performance characteristics listed in Table 18 and, no doubt, include some features not included in the list. However, many fertile areas for improvement remain.

Ongoing NASA R&T programs hold promise for improvements in several areas. Current efforts include:[2]

- Progress in improving aerodynamic efficiency (lift/drag ratio) of low-speed airfoils
- Investigations of helicopter rotor air foils
- Investigations of "synthetic" jet engine fuels
- Experimental programs involving clean combustion engines
- Investigations of piston engine emission reductions
- Aviation human factors research.

There remains, however, a need for special application of new as well as ongoing R&T efforts to agricultural aircraft. NASA could provide the necessary coordination for such an effort. The National Agricultural Aviation Association (NAAA) would support this effort and become an active participant.

DISPERSAL SYSTEM AND FLOW FIELD CHARACTERISTICS

Problems associated with agricultural aircraft dispersal system and flow field characteristics are in many ways as complex as aircraft design and performance characteristics problems.

Three problem areas concerning dispersal system and flow field characteristics included previously with basic aircraft problems are:

- The need for low profile drag application packages
- The need for safe and efficient chemical loading, carrying and dispersal systems
- The need to determine airfoil aerodynamic qualities which optimize wing-tip vortex impact on chemical dispersal patterns.

Each of these problems is discussed briefly in the following paragraphs.

Any application package appended to a basic airframe will contribute to total drag. The size and aerodynamic qualities of such a package will determine the amount of profile drag added to the total system. But while profile drag can not be eliminated, it can be reduced by design features. Reducing drag reduces the amount of thrust required. At low air-speeds, the increased angle of attack necessary to generate required lift results in increased drag which, as noted, generates greater thrust requirements. Ultimately, weight vs. lift and drag vs. thrust requirements reach a point where no further thrust is available. In order to operate an aircraft so as to have additional thrust available for safety and operating contingencies, trade-offs must be made so as to reduce thrust required under normal operations. Typically, this is accomplished by limiting gross weight, thereby reducing the lift requirement, which in turn permits a reduction in angle of attack and a commensurate reduction in drag. A reduction in drag through improved design can reduce the amount of gross weight reduction made necessary for safe operation of the aircraft. This is not a new concept. Aeronautical engineers have wrestled with such design problems for many years. The important point is that the same expertise should be directed toward improving the aerodynamic features of application packages appended to agricultural aircraft since they contribute to total system drag.

Unsafe and inefficient loading, carrying and dispersal systems are a hazard to pilots and to ground loading/servicing personnel, increase aircraft turn-around time, and cause chemical loss due to spillage and leakage.

Wing-tip vortex generation is an important factor in dispersal patterns. The impact of wing-tip vortices on dispersal patterns is not always detrimental. For example, vortex phenomena in creating an updraft is considered desirable for spraying citrus groves since the height and density of the trees limit penetration of the chemicals to the lower and inner parts of the trees. But most other types of spraying operations demonstrate a need for controlling wing-tip vortices to improve drift control.

Industry representatives have cited a number of equally important problems associated with dispersal

[2] NASA Fact Sheet, Release No. 75-65, March 1975.

system and flow field characteristics including:

- A need for increased delivery accuracy for row crops in order to minimize application overlap
- A need for accurate control of small droplet size to reduce the amount of base mixture required (thereby resulting in an effective increase in payload capacity)
- A requirement for systematic verification of dispersal system performance under various regimes of droplet size, aircraft speed and chemical type applied
- A requirement for development of nozzle and valve materials and techniques which allow precise and rapid shut-off
- A requirement for equipment and/or techniques to permit a wider swath at lower altitudes
- A need for uniform droplet size on path from aircraft to field
- A need for an accurate flagging system
- A need for determining better methods of drift control
- A need for methods of determining actual spray patterns
- A need for dissemination and practical application of known good results relative to dispersal systems
- A need for an overall spraying test program to establish the characteristics of present and proposed dispersal systems under various scenarios of operational and atmospheric parameters.

OPERATING CONSTRAINTS

The ag-air industry is subject to a number of constraints which are diverse in nature, impact unfavorably on current operations, and pose threats to future industry operations. In that regard, they represent problems to the ag-air industry and warrant investigation and/or R&T efforts to seek ways for minimizing their impact.

Some examples of constraints which pose current and/or future problems for the ag-air industry are:

- Weather phenomena
- Fuel availability
- Availability of fertilizers, herbicides and pesticides
- Environmental impact of chemicals.

Each of these is discussed briefly in the following paragraphs.

Akesson and Yates summarized the problem posed by weather conditions for ag-air operators:

> "The applicator must 'live with' the weather and try to confine his application to those times when wind velocity, direction and gradient, ambient temperature and temperature gradient, and relative humidity are favorable. Operationally this can be frustrating to the commercial applicator, who must try to accomplish the job to be done, frequently in spite of less favorable weather."[3]

It can be added that, at times, the weather is so unfavorable as to preclude operations altogether. Elaborating on these weather factors, Akesson and Yates point out that for various combinations of wind directions and velocities, air temperatures, wind and temperature gradients, and relative humidities, there are more favorable and less favorable droplet sizes, delivery altitudes and general application techniques. Add, too, the variables of crop type and/or reasons for application (air/ground insect control, leaf covering, ground fertilization), and the decisions to proceed or withhold application under various meteorological conditions grow more and more complex. Weather factors also modify aircraft performance which may, in turn, necessitate payload reductions and changes to normal inflight procedures.

National Oceanic and Atmospheric Administration Environmental Studies Service Centers are providing farmers in some states with advice on when to request aerial applications of pesticides based on wind and precipitation forecasts.[4] However, such advice is general in nature and does not provide all the information necessary for proper application.

To avoid penalties resulting from weather induced damage to adjacent fields or from ineffective applications, ag-air operators must make knowledgeable decisions in complex situations. As a result, there is a need for continuing R&T efforts to determine optimum systems and techniques for operations in favorable, marginal and unfavorable weather.

In 1973, a critical fuel availability problem developed. On 12 December 1973, mandatory allocations on all fuels were announced. Agricultural aviation was listed with general aviation at 90 percent of the 1972 base usage. On December 17, FEA decided to allow ag-air 100 percent of required fuel quantities. The decision, published 2 January 1974, was based on a USDA call for all-out agricultural production and on the fact that ag-air could help achieve that goal.[5]

It is conceivable that similar crises could develop in the future. If agricultural production were to be under

[3] Akesson, N. B. and Yates, W. B., *The Use of Aircraft in Agriculture*, FAO, United Nations, Rome, 1974.

[4] Weigel, E. P., *"Helping Farmers Outwit the Weather," World of Agricultural Aviation*, October 1975.

[5] *Ibid.*

curtailment at that time, ag-air could receive reduced fuel allocations necessitating curtailment of ag-air operations. This could cause some ag-air companies to fold and reduce efficiency among others. Then, if agricultural production goals were again raised to an all-out production level, ag-air might not be geared to support such an effort. This scenario suggests a need for continued R&T efforts to develop increasingly efficient engines with reduced fuel requirements; to develop application systems and techniques which will increase the acreage treated per flight hour; and to develop and disseminate information on optimal application conditions.

The availability of fertilizers, herbicides and pesticides is also a matter of great importance to the ag-air industry.

In 1973-1974, U.S. fertilizer demand exceeded available supplies.

On 19 July 1974, the U.S. Department of Agriculture issued a report[6] which stated the following:

> "Pesticide supplies were reported tight to acute in some counties in 44 states. Herbicide supplies were tight in over 22 percent of all agricultural counties, with an acute shortage in only one percent.
>
> "More that 18 percent of all agricultural counties reported tight supplies of insecticides, with only one percent reporting the supply situation acute.
>
> "Fungicide supplies were reported tight in nearly 16 percent of all agricultural counties, with slightly over one percent reporting an acute shortage."

On 5 December 1974, in a speech to the Senate, the Honorable Herman E. Talmadge noted that FEA and other nongovernmental experts projected continued shortages of farm chemicals in future years.

While concern has been expressed for the need to expand agricultural fertilizer and chemical production, it is likewise important for the ag-air industry to make maximum use of the fertilizers and chemicals available to them and to benefit from R&T efforts to develop increasingly effective and efficient systems and methods of application.

Environmental protection regulations have considerable impact on ag-air operations. Among the restrictions governing ag-air operations are:

- Tolerance limits for specific chemicals on various produce, including animal products
- Permit requirements for application of restricted herbicides and insecticides
- Specified regulations for nozzle types and sizes, operating pressures and nozzle placements on aircraft for application of chemicals in hazardous areas (areas with susceptible crops)
- Restrictions based on weather conditions
- General aircraft sprayer regulations.

In *The Use of Aircraft In Agriculture*, Akesson and Yates predict an increase in restrictions on agricultural aircraft primarily in two areas:

- Categorization and regulation of all pesticide use
- Regulations regarding the type of equipment used (basically the degree of spray atomization for drop-size controls), and the chemical formulation (such as the use of granular materials for minimum drift).

Dr. W. J. Maan, director general of the International Agricultural Aviation Centre, concurs with that prediction. He predicts that environmental protection will make various types of aerial application illegal.[7]

As restrictions increase, there is additional cause for establishing R&T effort to develop application system technologies which will eliminate the need for restrictions and, at the same time, allow maximum commitment of ag-air potential to agricultural production.

SAFETY OF PERSONNEL

Safety of personnel is a primary concern throughout the entire aviation industry. But some problems are of particular significance to ag-air. A number of such problems, mentioned by industry representatives and the authors cited, are listed below:

- Pilot fatigue
- Poor maintenance practices during peak operating periods[8]
- Continuous operations in close proximity to ground obstacles such as trees, power poles and power lines[8]
- Toxic inhalation of dust or spray owing to wind shifts and/or miscalculations[8]
- Dangers to flagmen[8]

[6] *U.S. World Fertilizer Situation*, a report prepared for the Committee on Agriculture and Forestry, United States Senate, 31 December 1974.

[7] Maan, Dr. W. J., "World Trends in Agricultural and Forestry Aviation," *World of Agricultural Aviation*, May 1975.

[8] "The Sky Farmer—How to Lower the Risks in Low Altitude Flying," *FAA Aviation News*, October 1975.

- Crashworthiness characteristics of ag aircraft[9]
- Continuous night operations in close proximity to the ground and ground obstacles[10]
- Communications among aircraft operating in close proximity to one another[10]
- Adequate medical surveillance of persons involved with hazardous chemicals[11]
- Casual attitude concerning long-term harmful effects of chemicals on personnel
- Failure to use protective equipment and safety equipment that is considered hot, uncomfortable and clumsy[10]
- On-scene knowledge of first-aid techniques[12]

Pilot fatigue is of special significance to ag-air and has long been considered a primary factor associated with accident rates. In *The Use of Aircraft In Agriculture*, Akesson and Yates cite the work of D. Baruch in 1970 in listing a number of factors contributing to fatigue among agricultural pilots:

> . . . "(a) frequent early morning operations, thus reducing the pilot's rest; (b) low-altitude flying, many obstructions, and frequent turbulent weather; (c) long working hours, multiple landings and take-offs (up to 10 or 15 per hour), and poor landing strips, which are frequently dusty and rough; (d) high-temperature working conditions and slip stream buffeting in open cockpit planes; and (e) exposure to toxic chemicals, which may impair the pilot's vision, increase his drowsiness, or interfere with his sense of balance and direction . . ."

Ongoing R&T efforts related to personnel safety are commonplace throughout aviation. However, there remains a need for R&T efforts specifically dedicated to enhancing the safety of personnel involved in ag-air operations.

[9] Barnes, Dr. A. C., "Crash Safety in Agricultural Aviation," *Aerial Applicator*, January 1967.

[10] Watson, Dr. M. and Benson, W. W., "Chronicle of a Crash: A Devastating and Avoidable Tragedy," *WAA*, October 1974.

[11] Morgan, D. P., M.D. and Roan, C. C., Ph.D., "Chemical Hazards to Ag Pilots," *World of Agricultural Aviation*, December 1974.

[12] *Steward, D., "Pilot Protection," World of Agricultural Aviation*, December 1974.

V. NASA ROLE IN AG-AIR

APPLICABLE NASA RESEARCH AND TECHNOLOGY

The National Aeronautics and Space Act of 1958 delineates NASA's role in aeronautics. The Act reads in part:[1]

> ". . . (c) The aeronautical and space activities of the United States shall be conducted so as to contribute materially to one or more of the following objectives:
>
> ". . . (2) The improvement of the usefulness, performance, speed, safety, and efficiency of aeronautical and space vehicles;
>
> ". . . (4) The establishment of long-range studies of the potential benefits to be gained from the opportunities for, and the problems involved in the utilization of aeronautical and space activities for peaceful and scientific purposes;
>
> ". . . (5) The preservation of the role of the United States as a leader in aeronautical and space science and technology and in the application thereof to the conduct of peaceful activities within and outside the atmosphere;"

In response to this congressional mandate, NASA has carried out a wide range of programs many of which, such as the Apollo space program, are well known to the general public. Less well known are NASA aeronautical R&T programs in support of improvements in general aviation.

A number of on-going NASA general aviation R&T efforts relate directly or indirectly to ag-air problem areas. As depicted in Figure 11, the results of NASA research in airfoil development, drag reduction, propulsion efficiency, crashworthiness and stall/spin characteristics are applicable to ag-aircraft as well as to other general aviation aircraft. Other NASA aeronautical R&T results (such as nozzle droplet formulation characteristics) may also apply directly or indirectly to ag-air application problems.

NASA SPECIAL SKILLS AND FACILITIES

In addition to specific research in ag-air program areas, NASA can bring to bear unique interdisciplinary systems analysis skills and facilities including:

- Simulators and computer skills to test new aircraft, dispersal system and flow field characteristics
- Wind tunnels to test promising designs
- Interagency cooperative programs to conduct field tests of dispersal characteristics
- Systems analyses to match technologies to the economic realities of the required operations
- Broadbased expertise in program management and coordination.

As noted earlier, new ag aircraft sales amount to approximately $50 million annually. While this figure is large, it will not support significant exploratory research and development efforts within the industry. NASA is uniquely qualified to conduct such efforts and, as indicated above, is already conducting research programs which have a high degree of transferability to ag-air problem areas. Such efforts would also fall well within NASA's congressionally mandated role in aeronautics.

[1] Public Law 85-568, 85th Congress, H. R. 12575, July 29, 1958.

AGRICULTURAL AVIATION PROBLEM AREAS

AIRCRAFT

- DESIGN/PERFORMANCE
- PROPELLERS
- AIRFOILS
- CORROSION
- WING TIP VORTEX PHENOMENA

APPLICATION SYSTEMS

- DESIGN/PERFORMANCE
- PROFILE DRAG
- UNIFORMITY OF COVERAGE
- NOZZLE SYSTEMS
- FLAGGING SYSTEMS
- EVALUATION AFTER APPLICATION

SAFETY

- FATIGUE/TEMPO OF OPS.
- COCKPIT ENVIRONMENT
- AIRCRAFT PERFORMANCE
- CRASHWORTHINESS
- PROTECTIVE GEAR
- CHEMICAL HANDLING SYSTEMS

OTHER

- WEATHER
- AVAILABILITY OF FUELS AND CHEMICALS
- REGULATIONS

APPLICABLE NASA RESEARCH AND TECHNOLOGY

- NASA AIRFOIL DEVELOPMENT
- DRAG REDUCTION
- PROPULSION EFFICIENCY
- CRASHWORTHINESS
- STALL/SPIN

FIGURE 11. AGRICULTURAL AVIATION PROBLEM AREAS AND APPLICABLE NASA RESEARCH AND TECHNOLOGY

POTENTIAL BENEFITS OF NASA R&T

Detailed analysis of the potential benefits of a NASA ag-air R&T program has not as yet been conducted. However, the work which has been accomplished provides insight regarding target areas within which some degree of benefit can be realized.

A NASA ag-air R&T program can contribute to:

- A reduction in the $75 billion annual world crop loss due to pests, plant diseases and weeds
- An increase in agricultural productivity through a combination of ag-air and other technological improvements (Ex: No-till farming)
- Reduced environmental impact from chemical applications due to increased precision of aerial applications
- A positive impact on the U.S. GNP and balance of trade
- Social benefits owing to reductions in illness and malnutrition among developing nations
- Improved energy conservation (air is potentially a more fuel conservative mode than ground application by a factor of 9 to 1)
- Improved U.S. posture in international ag-air marketplace.

As noted, these target areas for potential benefits are general in nature. A more detailed look at potential benefits is included in the following chapter, subsequent to the presentation of a proposed NASA ag-air R&T program plan.

VI. PRELIMINARY AG-AIR R&T PROGRAM PLAN

BACKGROUND

The findings of the ag-air study team prompted the development of a preliminary ag-air R&T program plan. Those findings can be summarized as follows:

- Ag-air is important and its importance is expected to grow
- Substantial ag-air problems exist
- Productivity increases are possible
- Strong rationale for NASA involvement exists
- Ag-air is apparently a high payoff area with potentially large social benefits.

It should be emphasized that the program plan presented here is a preliminary plan only. Detailed implementation plans are a matter for future development.

PROGRAM GOALS AND OBJECTIVES

Ag-air R&T program goals and objectives are presented in Figure 12. Improved aerodynamic and structural performance, increased distribution system accuracy, increased system efficiency and safety, improved environmental safeguards, and reduced energy consumption are examples of areas in which short-, mid- and long-term improvements can be expected.

OVERALL PROGRAM APPROACH

The ag-air R&T program plan will employ a systems analysis approach wherein the aircraft, dispersal system and flow field are considered a single system. Previously it was noted that most ag-air industry improvements have been of an ad hoc nature and have not provided adequate solutions to industry problems. The systems analysis approach is designed to reverse this trend and provide system-wide technological improvements.

As part of this program approach, results of ag-air mission and economic analyses will be integrated with aircraft and subsystem studies to define areas for potentially fruitful R&T efforts (Figure 13).

Inputs from other government agencies, such as the U.S. Department of Agriculture and the Environmental Protection Agency, and from industry representatives will be included in defining and implementing R&T efforts.

NASA research centers will conduct appropriate R&T programs ultimately resulting in open field tests, verifications and demonstrations.

REPRESENTATIVE RESEARCH AREAS

Representative aircraft, dispersal system and flow field research areas are depicted in Figures 14, 15 and 16.

The effect of flight path control on distribution accuracy (Figure 14) is representative of areas where aircraft improvements are possible through R&T efforts. Improved aircraft guidance and stability subsystems will enhance the ability of ag-operators to apply chemicals easily and accurately. NASA expertise in precise guidance, sensors, stability and control, and aircraft handling qualities would appear to have a high degree of transferability to the ag-air environment.

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Program Goals and Objectives

Program Goal

To contribute to the solution of world food problems through aeronautical technology.

Program Objectives

To develop new technology for short-, mid- and long-term improvements in Ag-Air performance that will impact favorably on agricultural productivity.

- Improved aerodynamic and structural performance
- Increased distribution system accuracy
- Increased system efficiency and safety
- Improved environmental safeguards
- Reduced energy consumption

FIGURE 12. PROGRAM GOALS AND OBJECTIVES

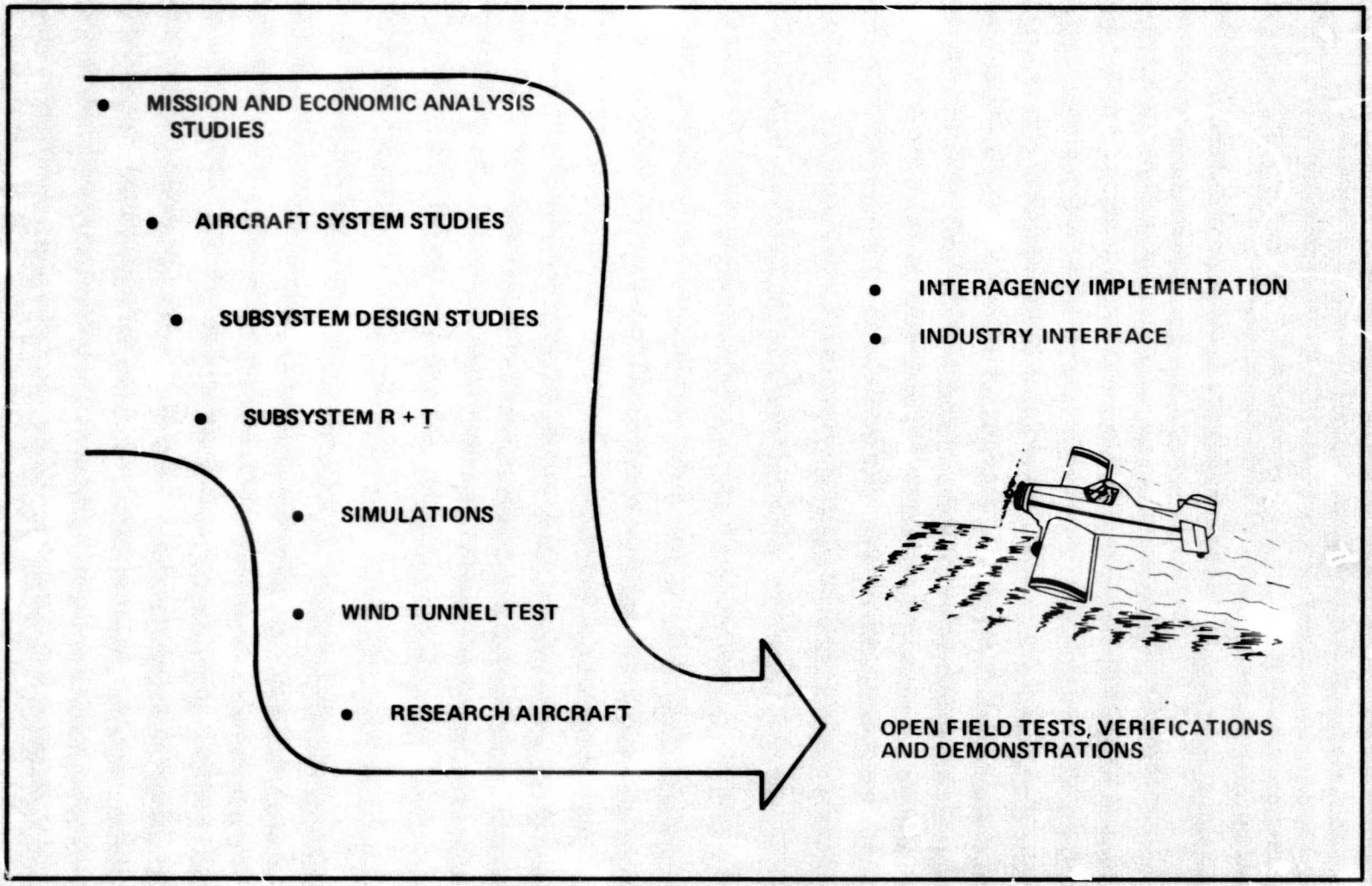
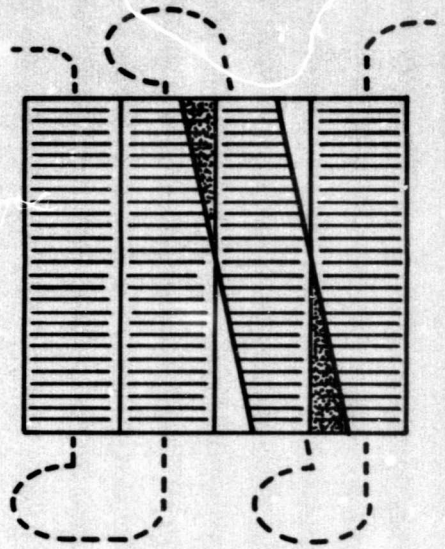


FIGURE 13. OVERALL PROGRAM APPROACH

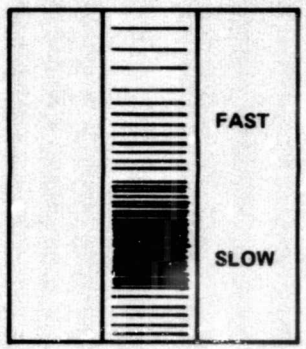
EFFECT OF FLIGHT PATH CONTROL ON DISTRIBUTION ACCURACY



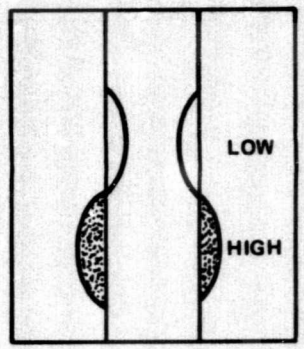
SWATH GUIDANCE

NASA EXPERTISE IN:

- PRECISE GUIDANCE
- SENSORS
- STABILITY AND CONTROL
- HANDLING QUALITIES



GROUND SPEED



ALTITUDE

FIGURE 14. AIRCRAFT SUBSYSTEM RESEARCH

Other aircraft subsystem research efforts will include those directed toward improvements in drag reduction, propulsion efficiency, corrosion control and cockpit environmental safety.

One factor of particular significance to the aircraft chemical system is the effect of droplet size on distribution accuracy (Figure 15). The size of the chemical droplet affects the time of fall and the evaporation rate as well as the wind effect on the droplet during fall. NASA expertise in designing nozzles which provide uniform droplet size may well be applicable to chemical dispersal systems. Other dispersal system research efforts will include those directed toward:

- Eliminating leakage and spillage
- Developing improved plumbing and valves
- Developing corrosion resistant materials
- Designing loading and handling equipment that is efficient and provides a greater measure of safety to ground personnel.

The aircraft flow field is another example of a factor which impacts on distribution accuracy (Figure 16). NASA expertise in vortex alleviation can prove useful in developing air foil and distribution system designs that will minimize the adverse effects of the aircraft flow field on distribution accuracy. Other flow field factors impacting on distribution accuracy which warrant research include weather phenomena, the nature of the crop, and the characteristics of the terrain being treated.

Research in the areas mentioned above can be expected to result in improvements which will provide:

- Improved operating efficiencies such as increased aircraft productivity and reduced energy consumption rates
- Long-term economic benefits such as increased world agricultural productivity
- Social benefits such as reduced environmental impact and world-wide health improvement through wide area pest control.

FUNCTIONAL PROGRAM ORGANIZATION

Figure 17 depicts the functional program organization for the ag-air R&T program. The program will be directed by the Associate Administrator, Aeronautics and Space Technology, and will be carried out as an integral part of the OAST General Aviation Program. An In-House Review and Advisory Group will monitor program plans and results. A separate Ad Hoc Committee on Ag-Air, composed of various government and industry representatives will actively participate in planning and monitoring the program.

NASA Research Centers, which have already contributed inputs to the development of this program plan, will continue to participate in further program planning as well as in the execution of specific research efforts.

OVERVIEW OF TECHNICAL PLAN

The NASA ag-air R&T program technical plan, presented in Figure 18, is designed to provide short-, mid- and long-term ag-air system improvements. The option exists, however, to include a research aircraft while at the same time continuing R&T efforts toward improving existing aircraft and aircraft systems.

The technical plan is also designed to include a detailed program definition phase wherein systems, economic and operations analyses will be performed to determine those research areas which offer the highest potential for ag-air improvments. The plan also allows two and one-half years to research design alternatives before making a go-ahead decision on a research aircraft.

Program control and integration will be provided by the Office of Aeronautics and Space Technology assisted by a lead center.

CENTER SUBSYSTEM RESEARCH AREAS

The ag-air R&T technical plan takes advantage of the skills, facilities and expertise available at each of the Research Centers. Figure 19 lists areas within which the Centers will conduct R&T efforts, with overall coordination provided by the Office of Aeronautics and Space Technology. Research areas listed are not intended to represent a complete list of activities included in the program.

In carrying out research in the areas shown, Langley Research Center is being considered for the role of lead center.

PROGRAM BUDGET SUMMARY

The Ag-Air R&T Program Budget Summary presented in Figure 20, allocates $35 million over an eight year period. The $35 million figure includes $10 million for the design, fabrication, test and evaluation of a flying test-bed if that is proven to be required. A decision to eliminate the research aircraft would reduce the program by $10 million but would not alter remaining program structures or goals. Initial funding will support detailed analyses with the intent of providing firm rationale for the full-scale program.

POTENTIAL BENEFITS OF PROPOSED PROGRAM PLAN

A previous section of this report listed some general benefits potentially available through NASA R&T. This

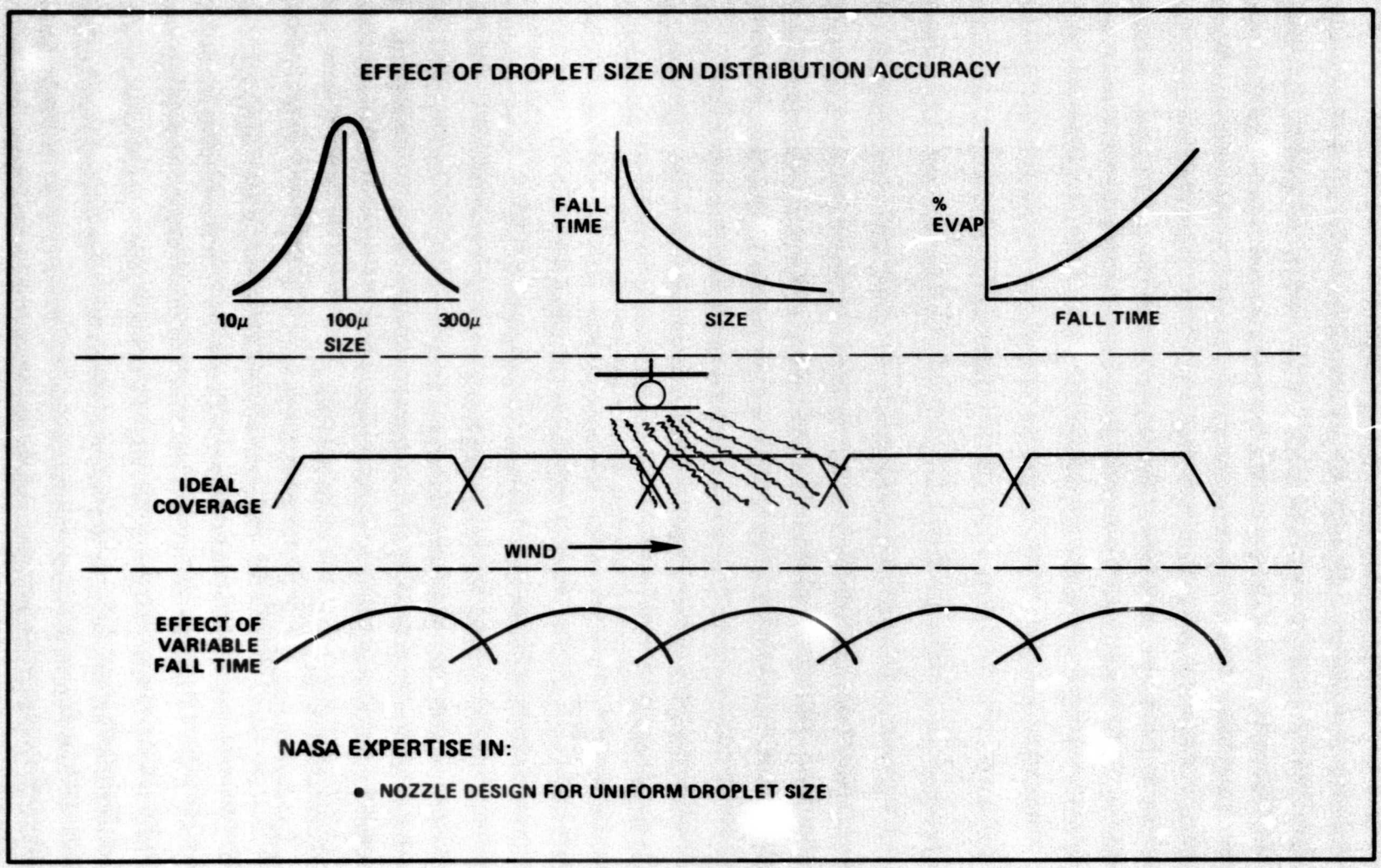
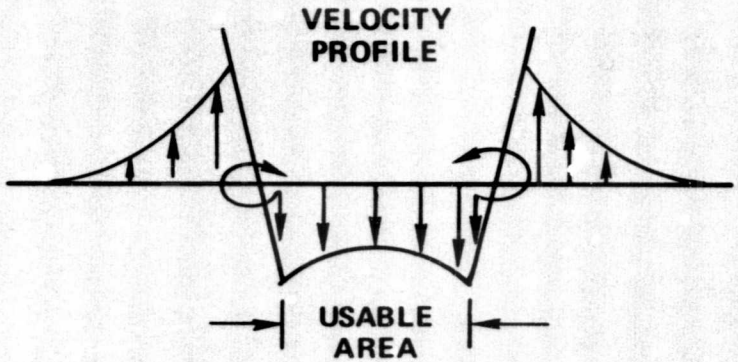


FIGURE 15. DISPERSAL SYSTEM RESEARCH

EFFECT OF AIRCRAFT FLOW FIELD ON DISTRIBUTION ACCURACY



NASA EXPERTISE IN:

- **VORTEX ALLEVIATION**

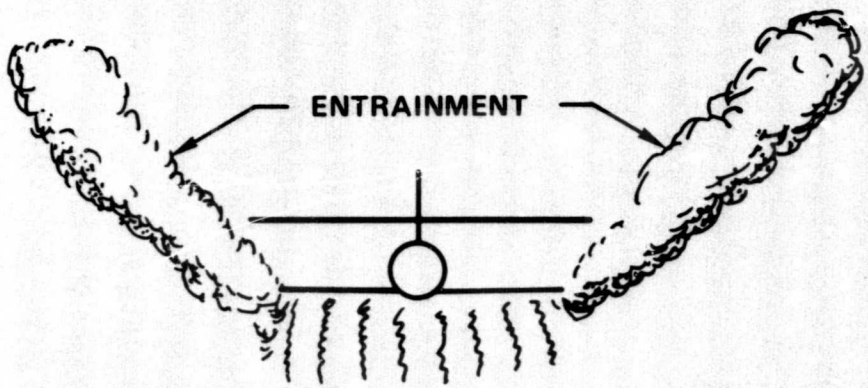


FIGURE 16. FLOW FIELD RESEARCH

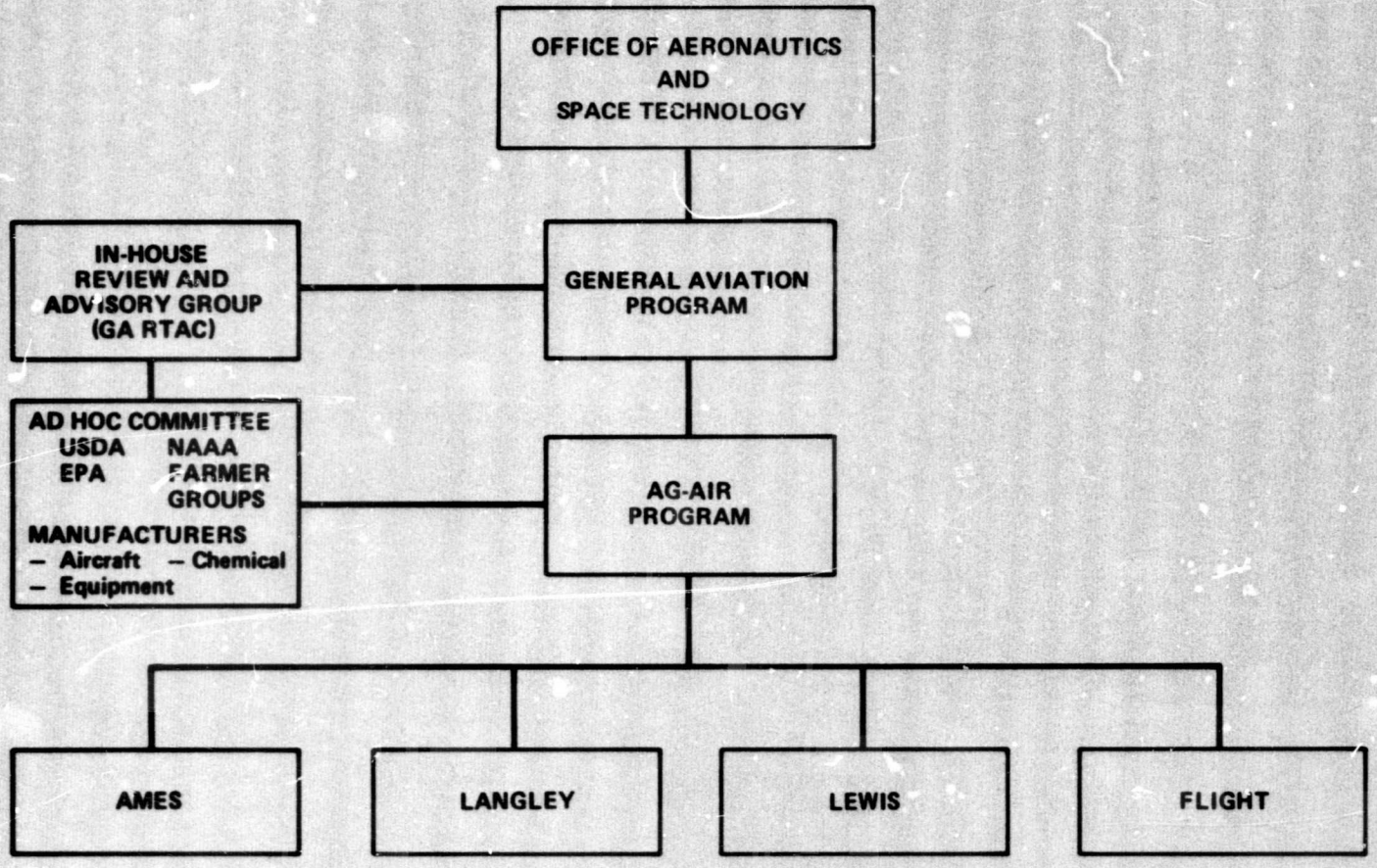


FIGURE 17. FUNCTIONAL PROGRAM ORGANIZATION

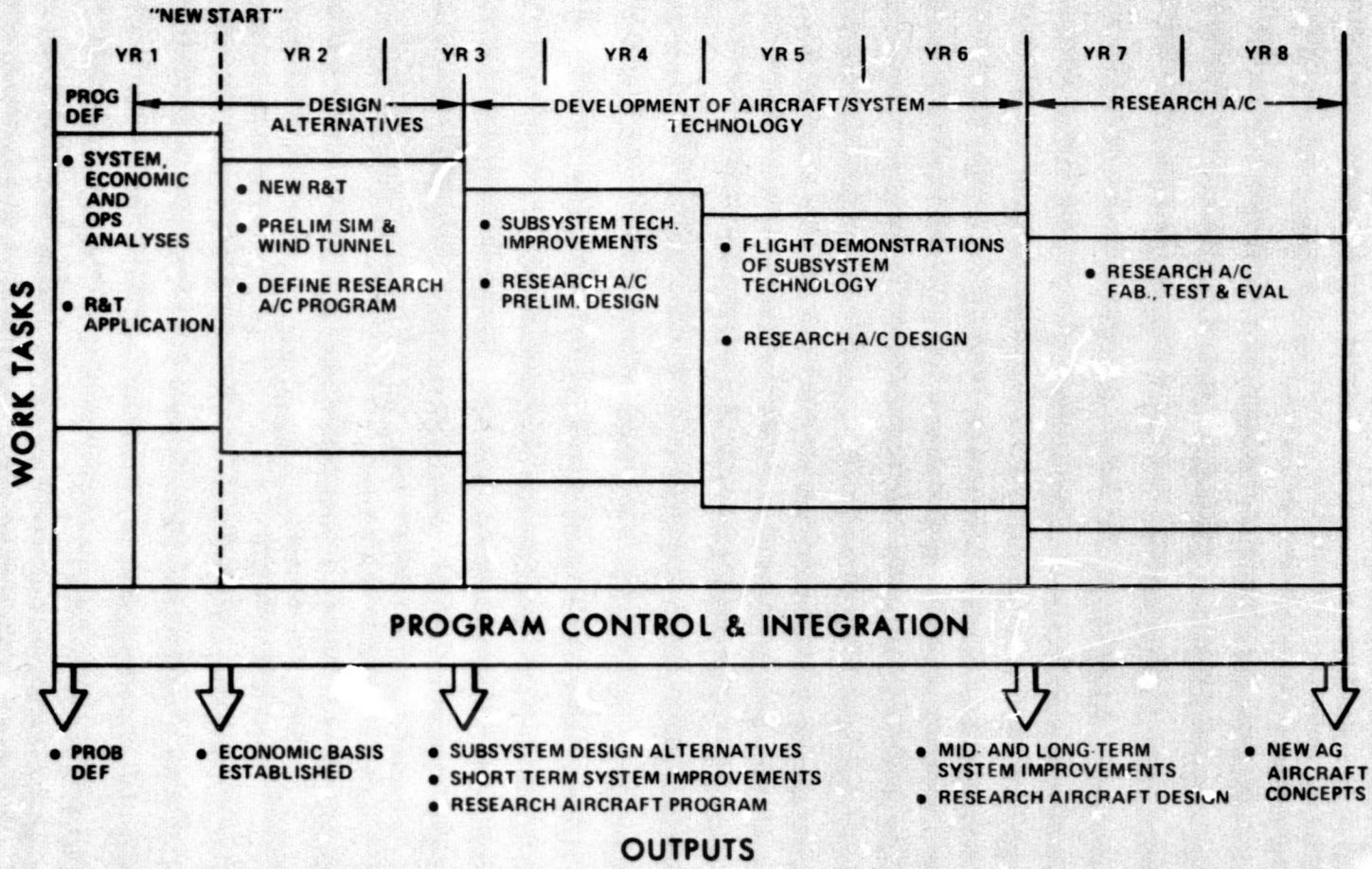


FIGURE 18. OVERVIEW OF TECHNICAL PLAN

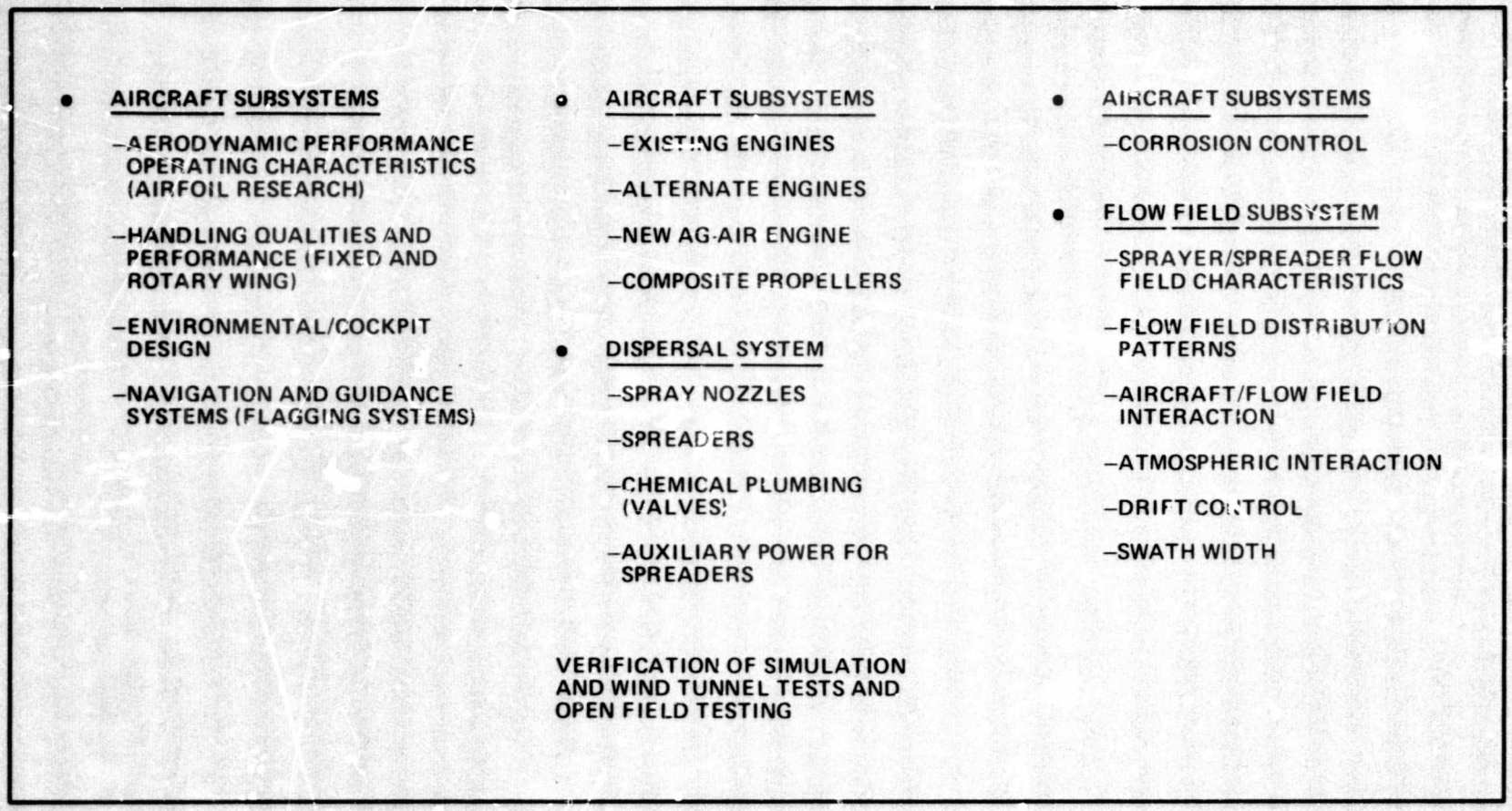


FIGURE 19. CENTER SUBSYSTEM RESEARCH AREAS

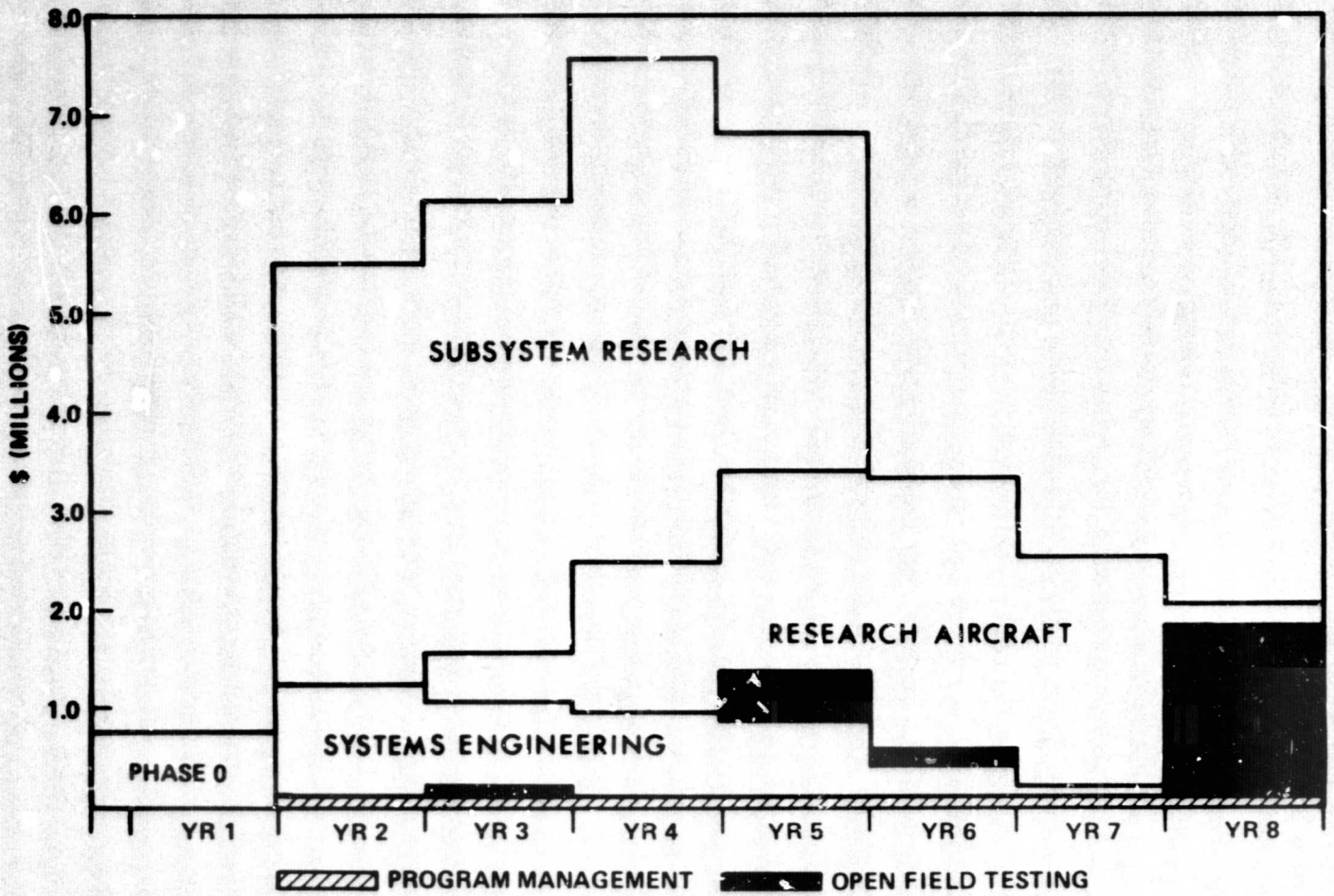


FIGURE 20. PROGRAM BUDGET SUMMARY

section describes some of the more specific benefits which could be derived through the proposed ag-air R&T program plan including:

- Increased aircraft productivity
- Savings in time and energy resources
- Increased yields and net returns

Note that these are preliminary analyses only. More detailed analyses will be conducted during the first phase of the program.

Increased Aircraft Productivity

A variety of factors influence the overall productivity of agricultural aircraft. Among them are the following:

- Field size
- Ferry distance
- Ferry speed
- Application speed
- Swath width
- Rate of application

The exact relationships among these and other variables, as well as their combined impact on agricultural aircraft productivity, are matters for further in-depth analyses. Similarly, potential benefits resulting from technological improvements, which appear to favorably influence the impact of these variables on aircraft productivity, should be the subject of in-depth benefit/cost analyses. Such detailed analyses, as noted above, are beyond the scope of this report.

On a preliminary basis, however, some simplified "if-then" projections can be made regarding the possible impact of selected variables on aircraft productivity. Such projections can at least provide points of departure for more detailed analyses. The following sections therefore include a number of "if-then" projections.

Field Size. Field size affects ag-air productivity in that larger fields permit longer swaths and therefore greater application times between turnarounds at the end of each swath. In a previous section it was pointed out that the average farm size in the United States has increased from 170 acres in 1940 to 380 acres in 1974. While data on average field size has not been obtained, larger farms may have the option of devoting larger tracts of land to a particular crop. *If* increasingly large tracts of land are devoted to particular crops, *then* ag-air productivity would appear to be enhanced.

Increasing field size does not necessarily rely on technological improvements. However, recommended field sizes to take advantage of technological improvements may be secondary outputs of R&T efforts.

In this section, a number of figures containing graphic depictions of potential ag-air productivity improvements include field size as one of the input variables, whereas productivity in acres per hour provides the measure of output.

Ferry Distance. Proximity of an operating field to the acreage under treatment impacts on ag-air productivity in that proximate fields reduce and remote fields increase unproductive ferry time. The task of establishing suitable operating fields to support ag-air operations is not within the scope of the ag-air R&T program. However, *if* R&T efforts result in improved aircraft short-field and rough-field performance, *then* field requirements could be reduced as well as the investment required to establish suitable operating fields. *If* the number of suitable operating fields is increased, *then* ag-air productivity could show a related increase.

Ferry Speed; Application Speed; Swath Width; and Rate of Application. Each of these factors is a variable which influences ag-air productivity. Ag-air productivity increases resulting from technological improvements in each of these areas are projected using a typical ag-aircraft currently in use as a base case.

Although a wide variety of aircraft are in use today, the type of aircraft selected for a discussion is considered to have the following characteristics:

- Chemical payload—2000 lbs.
- Ferry speed—100 mph
- Application speed—80 mph
- Swath width—50 ft
- Application rate—20 lbs/acre

In Figures 21-24, a series of "if-then" projections is graphically depicted. In each case, an improved value is assigned to one of the above variables, while the other variables listed remain constant. Productivity in acres per hour is plotted as a function of the selected variable and of field size.

Figures 21-24 are adapted from figures included in a report by Michael K. Smith.[1]

- *If* ferry speed is increased from 100 mph to 140 mph, and other variables remain constant, *then* the projected increase in aircraft productivity for various field sizes is as depicted in Figure 21.
- *If* application speed is increased from 80 mph to 120 mph, and other variables remain constant, then the projected increase in aircraft productivity for various, field sizes is as depicted in Figure 22.
- *If* swath width is increased from 50 ft to 80 ft, and other variables remain constant, *then* the projected increase in aircraft productivity for various field sizes is as depicted in Figure 23.

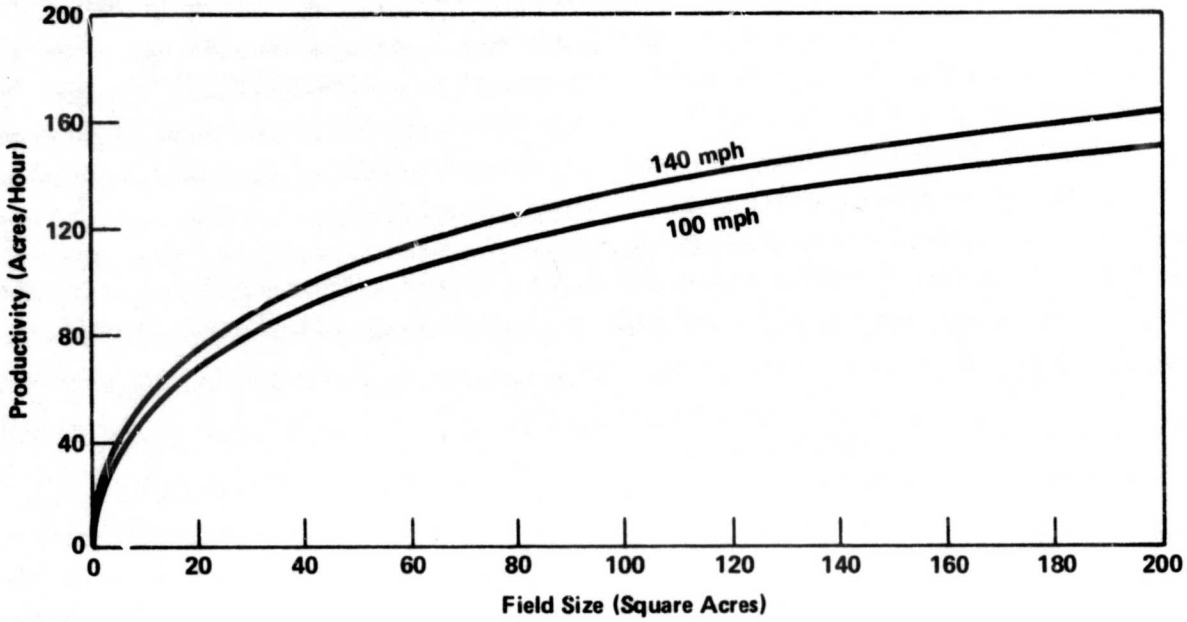


FIGURE 21. EFFECT OF INCREASE IN FERRY SPEED ON PRODUCTIVITY

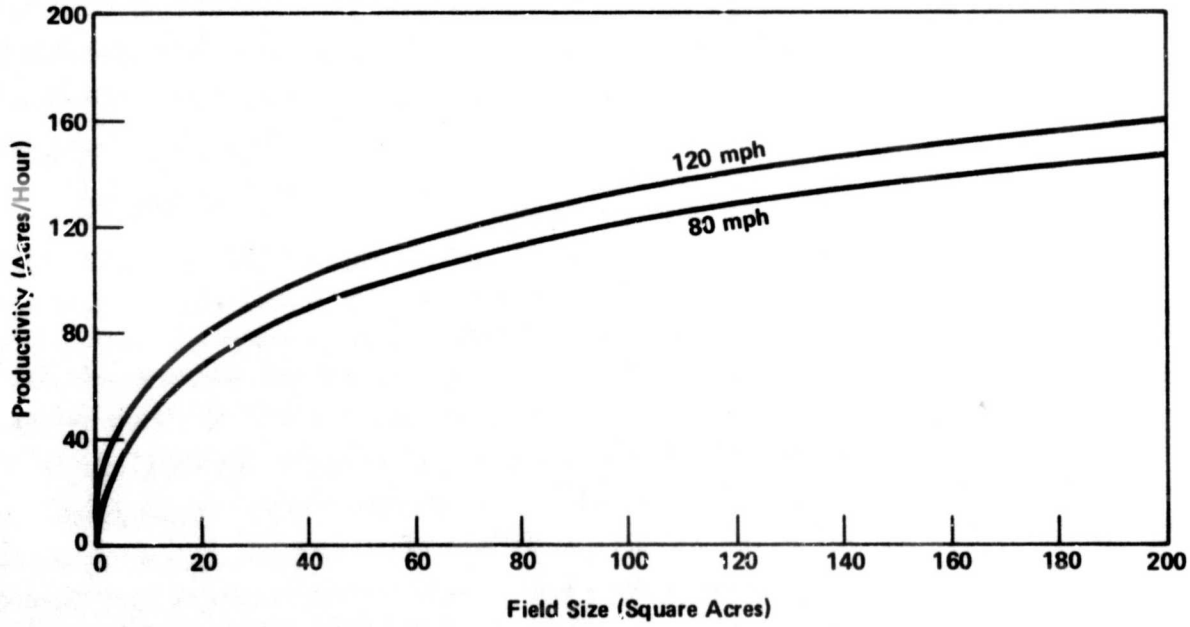


FIGURE 22. EFFECT OF APPLICATION SPEED ON PRODUCTIVITY

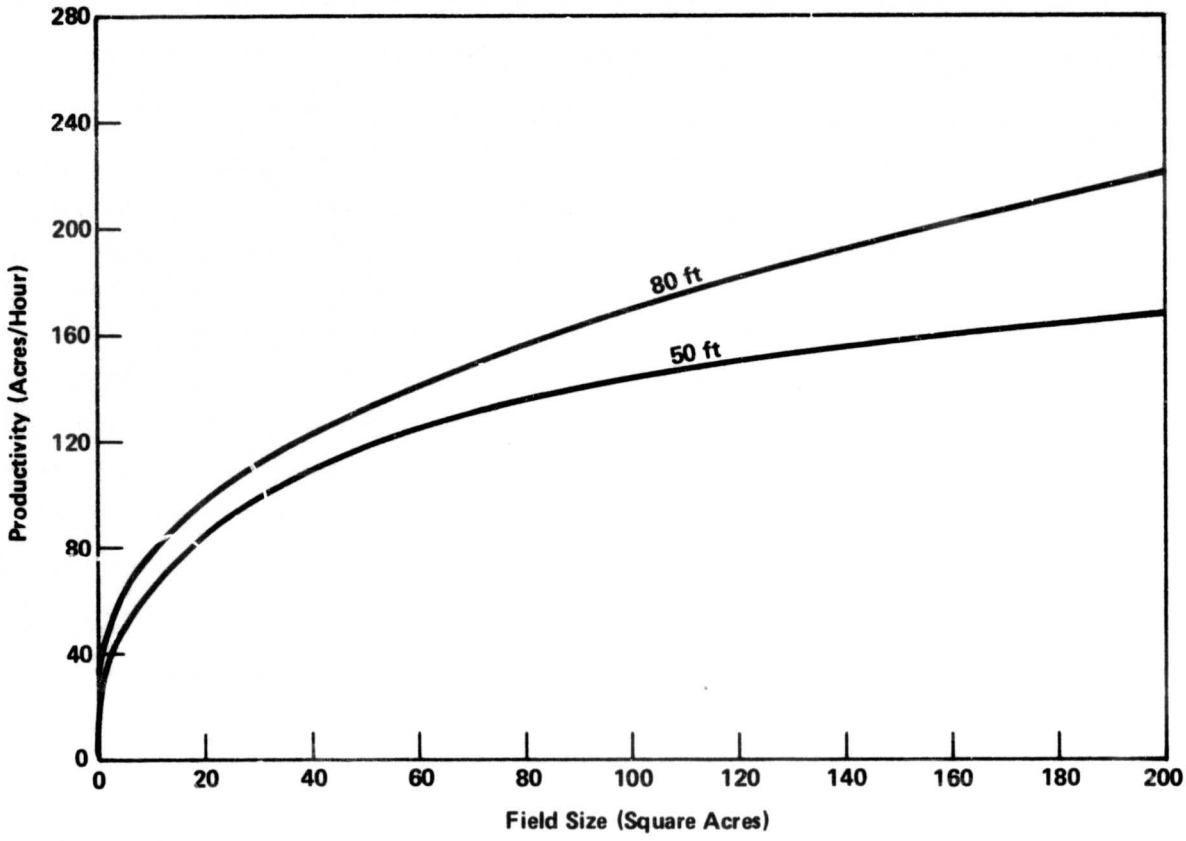


FIGURE 23. EFFECT OF INCREASE IN SWATH WIDTH ON PRODUCTIVITY

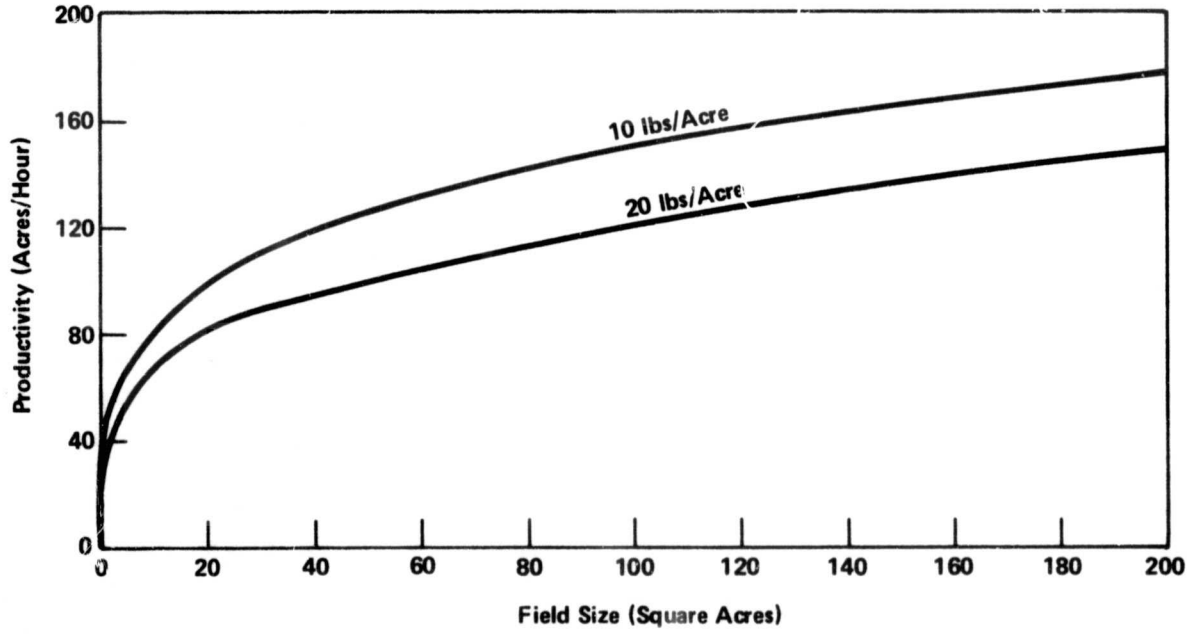


FIGURE 24. EFFECT OF DECREASE IN APPLICATION RATE ON PRODUCTIVITY

- *If* application rate is decreased from 20 lbs/acre to 10 lbs/acre (possibly indicating accuracy improvements resulting in reduced amounts of chemical required per acre for adequate coverage), and other variables remain constant, *then* the projected increase in aircraft productivity for various field sizes is as depicted in Figure 24.

Savings In Time and Energy Resources.

Time. Informed estimates by ag-air industry representatives indicate that, in general, a tractor requires one day (10 hrs) to accomplish what an ag-aircraft can accomplish in one hour.

Assuming the relative productivity rates for an ag-aircraft and a tractor remain constant, the times required for one ag-aircraft or one tractor to treat various acreages are listed in Table 19. Favorable conditions for either air or ground treatment are considered to be present.

Again assuming relative productivity rates for an ag-aircraft and a tractor remain constant, the number of aircraft or tractors required to treat various acreages within certain time constraints are as indicated in Table 20. Favorable conditions for either air or ground application are again considered to be present.

TABLE 19
TIME REQUIRED TO TREAT VARIOUS ACREAGES

Equipment	100 Acres	500 Acres	1000 Acres	10,000 Acres	20,000 Acres
1 Aircraft	1 hr	5 hrs	10 hrs	100 hrs	200 hrs
1 Tractor	1 day*	5 days	10 days	100 days	200 days
*1 day = 10 hours					

TABLE 20
EQUIPMENT REQUIREMENTS

Time Available	100A	500A	1000A	10,000A	20,000A
1 hr	1 aircraft 10 tractors	5 aircraft 50 tractors	10 aircraft 100 tractors	100 aircraft 1000 tractors	200 aircraft 2000 tractors
1 day*	.1 aircraft 1 tractor	.5 aircraft 5 tractors	1 aircraft 10 tractors	10 aircraft 100 tractors	20 aircraft 200 tractors
1 week*	.01 aircraft .16 tractors	.08 aircraft .83 tractors	.16 aircraft 1.66 tractors	1.66 aircraft 16.66 tractors	3.33 aircraft 33.33 tractors
* 1 day = 10 hrs; 1 week = 60 hrs; A = acres					

If the productivity rates of both aircraft and tractors are increased by 10, 25 or 50 percent, *then* the increased number of acres treated during various time intervals would be as indicated in Table 21. Favorable conditions for either air or ground treatment are considered to be present.

At current productivity rates, an ag-aircraft treats 1000 acres in 10 hours. A tractor treats 100 acres during the same 10 hours. Total output of the aircraft exceeds that of the tractor by 1000 − 100 = 900 acres. *If* the productivity rates for both aircraft and tractor are increased by 10, 25 or 50 percent, *then* total productivity of the aircraft exceeds that of the tractor by increasing amounts as indicated in Table 22.

Energy. Another informed estimate concerning ag-aircraft indicates that ag-aircraft are nine times more energy conservative than ground equipment.

In 1974, ag-air operations required 50 million gallons of fuel for treatment of 200 million acres. At a consumption ratio of 9:1, ground equipment would have required almost 0.5 billion gallons to treat the same number of acres.

At the current annual growth rate of 12 percent, ag-air operators will be treating 400 million acres in six years. Assuming little or no improvement in fuel consumption rates, ag-air fuel consumption would increase to 100 million gallons per year. At present consumption rates, ground equipment would require almost 1 billion gallons to treat the same number of acres.

TABLE 21
EFFECT OF INCREASED PRODUCTIVITY RATES ON ACREAGES TREATED

Equipment	Productivity Rate	1 hr	5 hrs	10 hrs	100 hrs	200 hrs
1 Aircraft	Current	100A	500A	1000A	10,000A	20,000A
	+10%	110A	550A	1100A	11,000A	22,000A
	+25%	125A	625A	1250A	12,500A	25,000A
	+50%	150A	750A	1500A	15,000A	30,000A
1 Tractor	Current	10A	50A	100A	1,000A	2,000A
	+10%	11A	55A	110A	1,100A	2,200A
	+25%	12.5A	62.5A	125A	1,250A	2,500A
	+50%	15A	75A	150A	1,500A	3,000A

A = Acres

TABLE 22
10 HOUR OUTPUT OF AIRCRAFT AND TRACTOR
AT INCREASED PRODUCTIVITY RATES

Productivity Rate	Acreage Treated		Aircraft over Tractor by:
	Aircraft	Tractor	
Current	1000	100	900A
+10%	1100	110	990A
+25%	1250	125	1125A
+50%	1500	150	1350A

A 10 percent reduction in ag-aircraft fuel consumption rates, while maintaining existing productivity rates, will obviously add to energy conservation efforts. But the most significant energy savings would appear to be those that could result from replacing ground applications with aerial application. Technological improvements resulting in increased demand for aerial application of chemicals could therefore enhance energy conservation efforts on a fairly large scale.

Increased Yields and Net Returns

Information on increased yields and net returns resulting from ag-air operations is sketchy at best. However, simplified "if-then" projections regarding yields and net returns can be made based on test cases. Two such cases involving soybeans and potatoes are discussed below.

Soybeans. In 1973, Dr. Walter Walla, a plant pathologist from the Texas Cooperative Extension Service at Texas A&M, discovered that the use of foliar fungicides on soybeans controlled pod and stem blight and increased the yield per acre by eight bushels. He also determined that the proper time for fungicide applications occurred at a time when plants were too large to take most ground equipment into the field. Aerial application was therefore the most appropriate means for applying the fungicides.

In the Southern Plains growing region (Texas and Oklahoma), soybean production in 1973 was as indicated in Table 23.

If foliar fungicides had been added to the soybean crop in the Southern Plains region increasing yields in Texas to 38 bushels per acre, and in Oklahoma to 31 bushels per acre, *then* the total soybean yield in that region might have increased as indicated in Figure 25.

The increased cost of adding foliar fungicides to the soybean is estimated at $5.00 per acre. *If* again, the region had been treated with foliar fungicides, and assuming that demand for soybeans warranted unlimited production, *then* the net additional return to the growers might have increased as indicated in Figure 26.

The Department of Agriculture estimates that 56 million acres of soybeans were planted in 1975. The national average yield per acre is approximately 28 bushels per acre. *If* foliar fungicides had resulted in a 5 bushel per acre yield increase, *then* the total yield for all soybeans might have increased by 280 million bushels.

Potatoes. In 1970, Canadian researchers investigated yields of potatoes on farms where both aircraft and ground machinery were used for spraying.[1] The fields sprayed by aircraft varied in size from 40 to 150 acres; those sprayed by ground equipment from 15 to 25 acres. Aerial spraying resulted in yields of 149 barrels per acre whereas ground application methods resulted in yields of 142.5 barrels per acre. The average price per barrel to the farmer was $2.60. Although the cost per acre for aerial application exceeded the cost per acre for ground application ($22.85 per acre vs. $14.87 per acre), increased yields from aerial applications resulted in an average income gain per acre of $8.92.

TABLE 23
1973 SOYBEAN PRODUCTION-SOUTHERN PLAINS

State	Acreage Harvested (000)	Yield Per Acre (Bushels)	Price Per Bushel	Value of Production (000)
Texas	261	30	$6.65	$52,070
Oklahoma	219	23	$6.65	33,496
			Total	$85,566

[1] Philpotts, L. E., "Aircraft Versus Ground Methods for Spraying Potatoes in New Brunswick," *Canadian Farm Economics*, Vol. 6, No. 4.

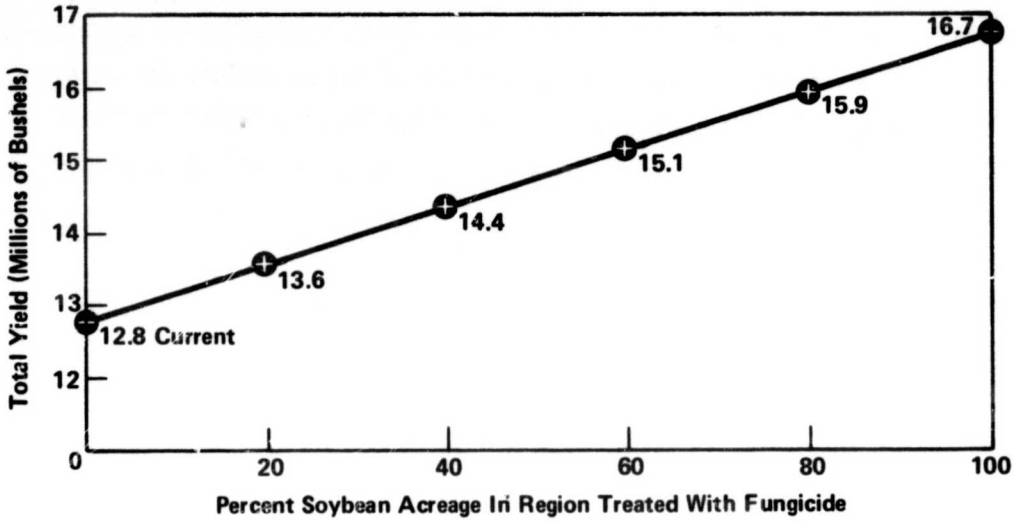


FIGURE 25. POTENTIAL SOYBEAN TOTAL YIELD INCREASES WITH FUNGICIDE APPLICATION

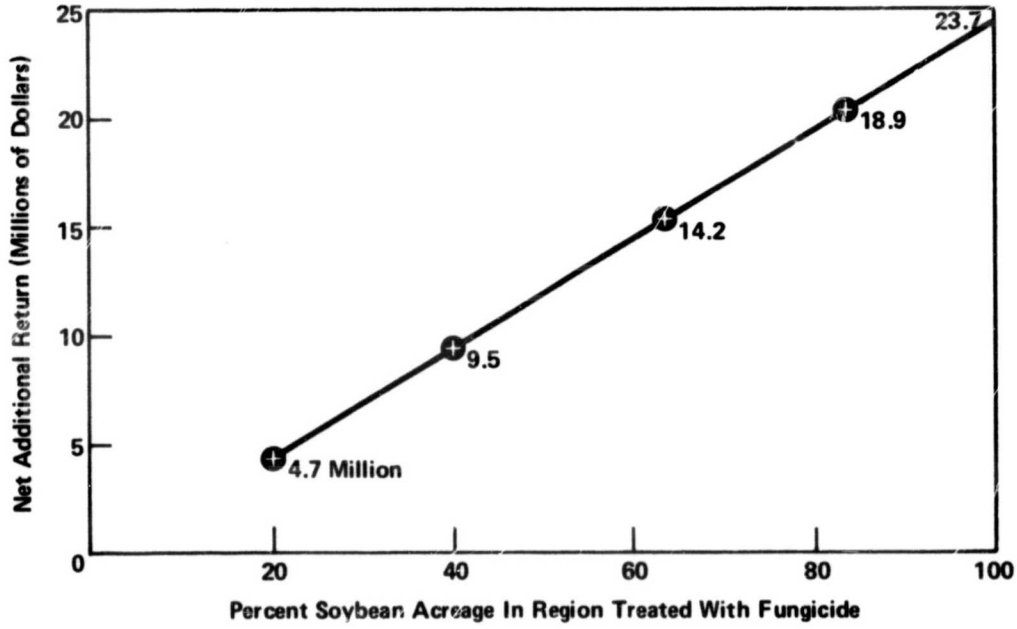


FIGURE 26. POTENTIAL NET ADDITIONAL RETURN TO GROWERS AFTER FUNGICIDE TREATMENTS

In the United States, approximately 1,381,000 acres of potatoes are harvested each year. *If* 10, 20 or 30 percent of the U.S. potato crop were to experience similar yield increases (5 percent), *then* total yield would increase as indicated in Figure 27 and additional income gained would be as indicated in Figure 28.

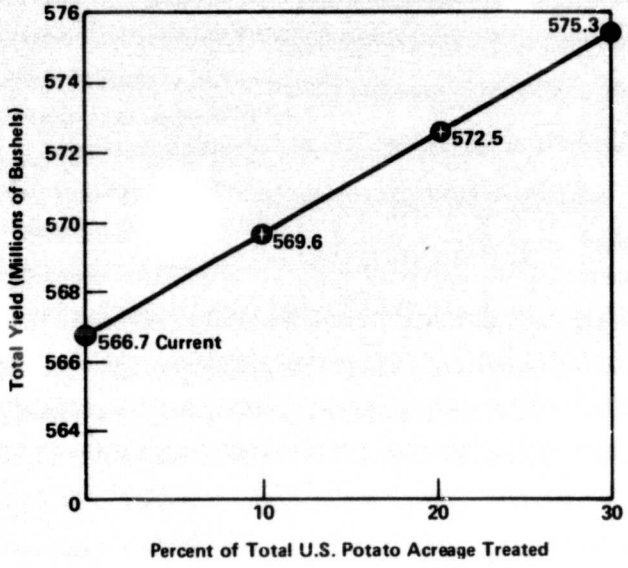


FIGURE 27. POTENTIAL TOTAL YIELD OF U.S. POTATO CROP IF AERIAL APPLICATION METHODS EMPLOYED

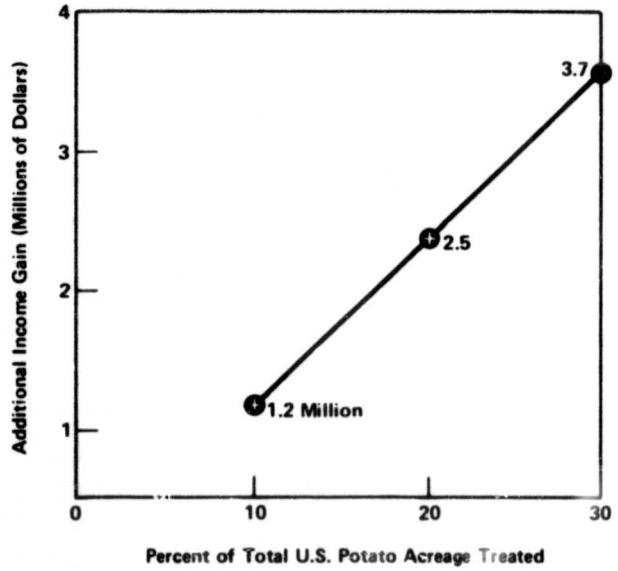


FIGURE 28. POTENTIAL ADDITIONAL INCOME IF AERIAL APPLICATION METHODS EMPLOYED

National Implications of Potential Benefits

Unit increases in aircraft productivity, in time and energy resources saved and in increased yields and net returns, would appear to indicate that we can "do better" than we are at present. "How much better" is a matter for further evaluation as indicated earlier.

Measures which yield greater energy conservation are certainly in accord with national goals.

Wide area pest control applications contribute to national health and help eliminate wide-spread damage to crops and natural resources.

In previous sections, it was pointed out that agricultural productivity is expected to become a matter of increasing national and world-wide importance. Agricultural aviation is seen as a major contributor to increased agricultural productivity. The relationship between agricultural productivity and the national economy is, however, extremely complex. While they appear mutually supportive, further analytical efforts are necessary to establish the true benefits and costs of productivity-enhancing programs. Plans to execute such analytical efforts are part of the ag-air R&T program plan.

POTENTIAL RECIPIENTS OF PROGRAM BENEFITS

An ag-air R&T program offers potential benefits to a variety of groups including:

- Farmers
- Ag-air operators
- Aircraft manufacturers
- Chemical manufacturers
- Consumers
- General public

Potential benefits can be related to the needs of interest to various groups. Some representative needs are listed in Table 24. An ag-air R&T program which results in technologically improved aircraft that can apply chemicals to larger acreages, at less cost, with greater accuracy, with reduced environmental impact, and with less energy consumption, would appear to be in the best interests of a variety of groups.

Current Users of Aerial Application Methods

Data from USDA Economic Research Service reports indicate that growers of the crops listed in Table 25 are currently employing aerial application services. (The precise crops within each category labeled "Other - - - -" that are currently treated by ag-aircraft has not yet been determined.)

TABLE 24
GROUPS VS. PERCEIVED NEEDS

Groups	Reduced Costs	Timely Treatments	Accurate Treatments	Energy Conservation	Reduced Environmental Impact	Lower Food Prices	Industry Expansion
Farmers	X	X	X	X	X		
Ranchers	X	X		X	X		
Forresters	X	X		X	X		
Ag-air operators	X		X	X	X		X
Aircraft manufacturers							X
Chemical manufacturers					X		X
Consumers						X	
General public				X	X	X	

TABLE 25
CROPS CURRENTLY EMPLOYING AERIAL APPLICATION SERVICES

Corn	Other Grains	Other Field Crops	Other Vegetables	Other Fruits & Nuts
Cotton	Oats	Grass and hayseed	Cabbage	Grapes
Wheat	Mixed grains	Buckwheat	Carrots	Avocados
Sorghum	Barley	Castorbeans	Celery	Figs
Rice	Rye	Hops	Lettuce	Blackberries
Soybeans		Lentils	Onions	Blueberries
Tobacco	Other Deciduous Fruits	Millet	Tomatoes	Boysenberries
Peanuts	Peaches	Mung beans	Watermelons	Currants
Sugarbeets	Pears	Peppermint	Sweet corn	Gooseberries
Alfalfa	Cherries	Spearmint	Snap beans	Loganberries
Pasture	Apricots	Rutabagas	Spinach	Raspberries
Potatoes	Plums	Sesame	Artichokes	Strawberries
Citrus	Prunes	Spelt	Asparagus	Almonds
Apples	Nectarines	Sunflowers	Broccoli	Filberts
Summerfallow		Velvetbeans	Cauliflower	Pecans
	Other Hay and Forage	Dry beans	Cucumbers	Walnuts
	All hay other than alfalfa	Dry field peas	Beets	Olives
		Flax	Green peppers	Tung nuts
		Popcorn	Green peas	
		Broomcorn	Cranberries	
		Cowpeas		
		Sugarcane		
		Sweetpotatoes		

Figure 29 is a map of the United States which identifies ten growing regions. Principal crops grown in each region are listed in Table 26. While data on the use of ag-aircraft by region has not been obtained, the crops grown in the various regions give some indication of where ag-air may be in use.

TABLE 26
PRINCIPAL CROPS BY GROWING REGION

Pacific	Mountain	Northern Plains	Southern Plains	Lake States	Corn Belt	Delta States	Northeast	Appalachian	Southeast
Cotton	Wheat	Corn	Cotton	Corn	Corn	Cotton	Other Hay & Forage	Soybeans	Cotton
Wheat	Other Grains	Wheat	Wheat	Soybeans	Wheat	Soybeans	Potatoes	Cotton	Soybeans
Sugarbeets	Other Hay & Forage	Sorghum	Other Hay & Forage	Tobacco	Sorghum	Rice	Other Vegetables	Other Hay & Forage	Other Vegetables
Alfalfa	Potatoes	Alfalfa	Rice	Alfalfa	Soybeans		Apples		Citrus
Potatoes	Pasture	Other Hay & Forage	Pasture	Other Vegetables	Other Hay & Forage				Peanuts
Other Vegetables	Summer-fallow	Other Grains		Other Field Crops	Other Vegetables				
Citrus		Other Field Crops		Other Grains	Other Grains				
Apples		Summer-fallow							
Rice									
Other Deciduous Fruits									
Other Fruits & Nuts									

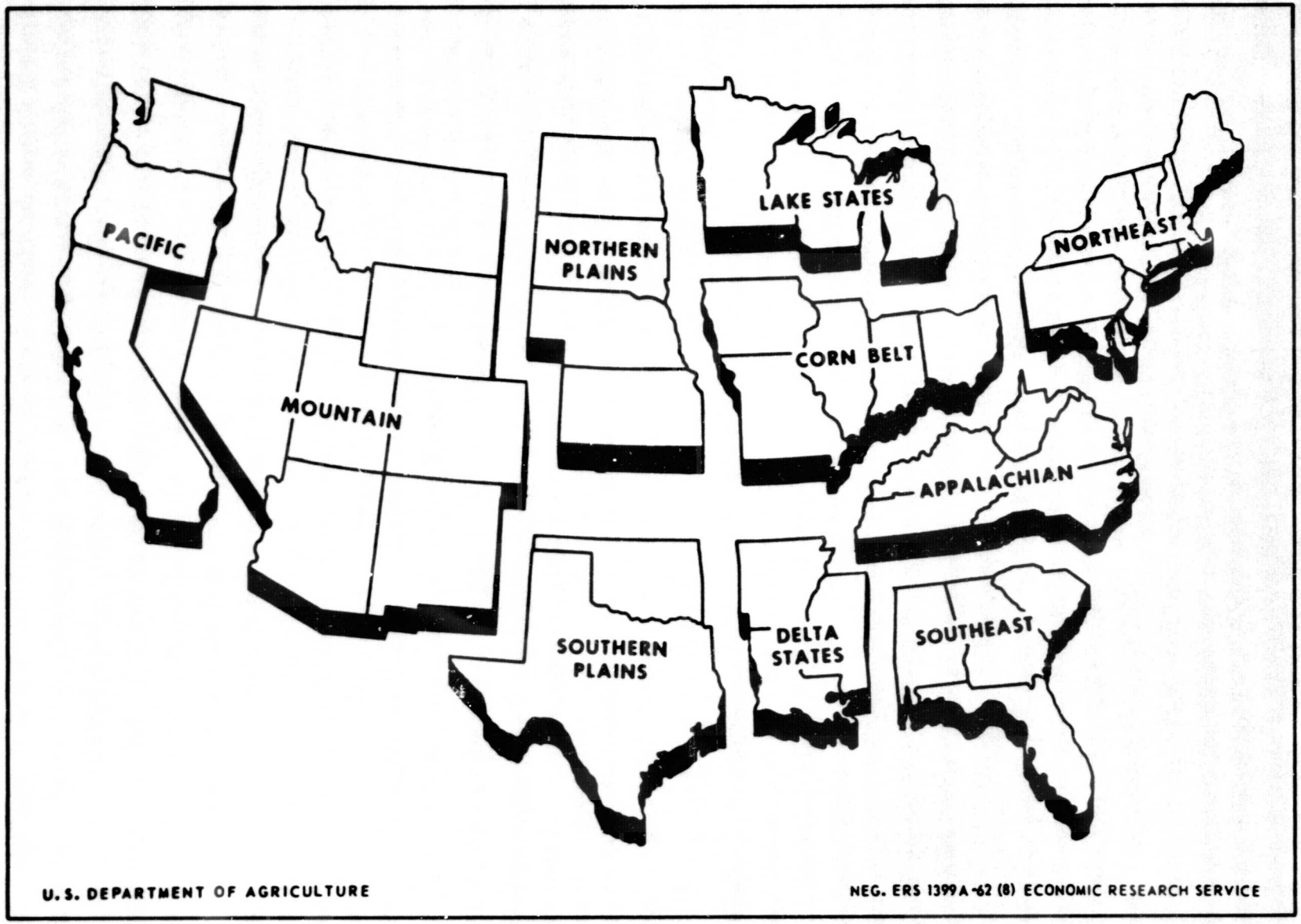


FIGURE 29. FARM PRODUCTION REGIONS

VII. SUMMARY AND NEXT STEPS

AG-AIR STUDY

The findings of the ag-air study indicate that:

- Ag-air is important and its importance is expected to grow
- Substantial ag-air problems exist
- Productivity increases are possible
- Strong rationale for NASA involvement exists
- Ag-air is apparently a high payoff area with potentially large social benefits.

NASA is seen to have the skills, facilities and expertise to execute a potentially fruitful R&T program and such a program falls well within NASA's charter.

The ag-air R&T program will contribute to:

- A reduction in the $75 billion annual world crop loss due to pests, plant diseases and weeds
- An increase in agricultural productivity through a combination of ag-air and other technology improvements such as no-till farming
- A reduction in the environmental impact of chemical application due to increased precision of aerial application
- A positive impact on the U.S. GNP and balance of trade
- Social benefits in the reduction of illness and malnutrition in developing nations
- Increased energy conservation since air is potentially a more fuel conservative mode than ground application by a factor of 9 to 1
- Improved U.S posture in the international ag-air marketplace.

AG-AIR PROGRAM PLAN

The findings of the ag-air study team prompted development of a proposed ag-air R&T program plan.

The proposed program plan, as presented, employs a systems analysis approach wherein the aircraft, dispersal system and flow field are considered as a single system. Thirty-five million dollars are allocated to various research areas and include $10 million for a flying test bed if that is proven to be required.

The proposed program will be directed by the Associate Administrator, Aeronautics and Space Technology and will be carried out as an integral part of the OAST General Aviation Program. All four NASA Research Centers will participate with Langley Research Center being considered for the role of lead center. An In-House Review and Advisory Group will monitor program plans and results, and a separate Ad Hoc Committee, composed of various government and industry representatives, will actively participate in planning and monitoring the program.

Objectives of the program are to develop new technology for short-, mid- and long-term improvements in ag-air performance that will impact favorably on agricultural productivity and support the overall program goal of contributing to the solution of world food problems through aeronautical technology.

NEXT STEPS

The immediate task to be undertaken next is to develop a detailed plan for proceeding with the program definition phase of the plan. This phase will include systems, economic and operations analyses designed to

determine those research areas which offer the highest potential for ag-air improvements. Emphasis will be placed on determining the true benefits and costs of productivity enhancing programs and on analyzing the relationships of variables which appear to impact an ag-aircraft productivity.

APPENDIX A
AVIATION DATA BASE SUPPORT FOR AG-AIR PROGRAM PLANNING

The Aviation Data Base used in conjunction with the General Electric Management Analysis and Projection (GEMAP) Service provides both useful data and analytic capabilities to perform simple and complex analyses. The system capabilities include tabulation, plotting and graphing time series, autocorrelation, correlation, curve fitting, percent change and regression analysis. These analytical capabilities hold promise as valuable tools for planning, forecasting and evaluating programs.

Variables presently contained in the aviation data base which were relevant to the ag-air study and to the development of the proposed ag-air R&T program plan are listed in Table A.1.

TABLE A.1
AVIATION DATA BASE VARIABLES
RELEVANT TO AG-AIR STUDY
AND PROGRAM PLANNING

Gross National Product (GNP)
Farm Business GNP
Real Farm Business GNP
Agricultural Employment
Farm Residential Structures
Accidents Per 100 Million Miles
Rates of Return
Farm Proprietors Income

The plotting and graphing capabilities of the GEMAP system are demonstrated in Figures A.1 and A.2. Figure A.1 displays GNP and Farm Business GNP, providing useful data as well as illustrating the relationship between the two indicators. Figure A.2 illustrates the cyclical yet overall upward trend of Real Farm Business GNP. Figures A.3 through A.7 display other variables listed in Table A.1.

A significant quantity of other data pertaining to agricultural aviation was collected from various sources. Such data could be added to the Aviation Data Base and thus be made readily available for use in future economic and cost/benefit analyses. NASA planners may also be able to make use of the more complex analytic capabilities of the GEMAP system.

Table A.2 provides a list of additional variables which could be entered into the data base for continued use in support of the ag-air program.

TABLE A.2
ADDITIONAL VARIABLES RELEVANT TO
AG-AIR PROGRAM

U.S. Statistics
Miles flown by ag-aircraft
Hours flown by ag-aircraft
Number of ag-air operators
Number of ag-aircraft
Number of ag-air pilots
Acres treated by ag-aircraft
Ag-aircraft fuel consumption
Accidents involving ag-aircraft
Fatalities from ag-air accidents
Acres in cultivation
World Statistics
Number of ag-aircraft
Acres treated by ag-aircraft
Acres in cultivation

NO-TILL FARMING TRENDS

In the course of the ag-air study, new farming techniques were examined to determine their potential impact on the use of ag-aircraft. No-till farming was identified as a technique having broad implications for ag-air.

Data collected for use in estimating the impact of no-till trends on ag-air were not available in the Aviation Data Base files. However, such data provides an excellent example of the type of information which can be added to the data base and made available for future use. ORI entered relevant data into the Aviation Data Base files where it can now be accessed as required. Examples of data entered include:

- Total acres treated by ag-air (Figure A.8).
- Projected acres farmed by no-till methods (Figure A.9).
- Projected acres treated by ag-aircraft (Figure A.10).

Figure A.8 totals for acres treated by ag-aircraft reflect multiple applications.

In Figure A.10 the data point for 1974 indicates 200 million acres (multiple applications) were treated by ag-aircraft. Data for subsequent years include a constant total of 200 million acres for existing ag-air operations plus the additional acres resulting from projected increases in no-till techniques. No-till totals are calculated at the rate of one additional application per acre. In reality, the number of acres treated by ag-air, exclusive of no-till trends, can be expected to increase at some as yet undetermined rate. On the other hand, the projected increases in no-till acreage will include some number of acres presently being cultivated by conventional techniques and which are already being treated by ag-air. The analysis is therefore incomplete and will require in-depth study to develop more realistic projections. Determinations will be required relating to:

- The rate of increase of total acres treated by ag-air exclusive of no-till trends (analysis would involve identification of primary factors driving ag-air growth)
- Number of acres currently treated by ag-air and cultivated by conventional methods which are likely to be included in no-till programs
- Average number of applications per acre under no-till techniques (considered above as one per acre but the actual number is expected to exceed this figure).

The data tabulations depicted graphically in Figures A.8-A.10 can be generated through simple computer terminal procedures. The more complex analytic routines necessary to support in-depth analyses of the impact of no-till farming on ag-air can also be carried out through existing Aviation Data Base and GEMAP system programs.

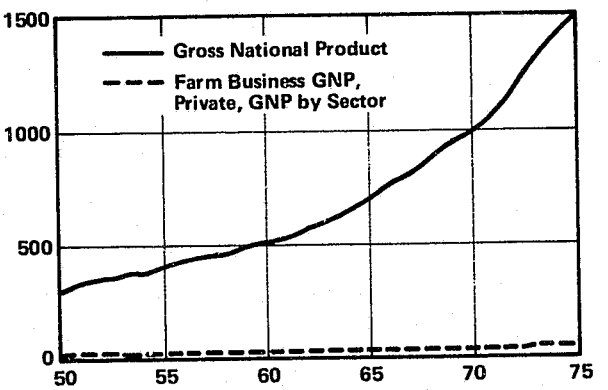


FIGURE A.1 GROSS NATIONAL PRODUCT

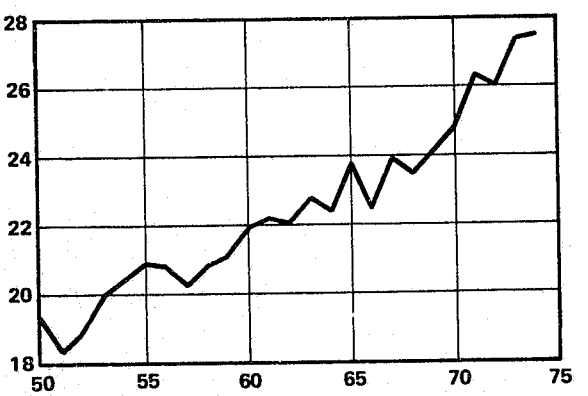


FIGURE A.2 REAL FARM BUSINESS GNP

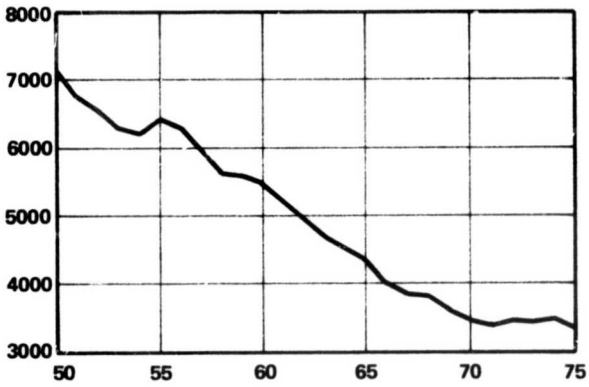


FIGURE A.3 AGRICULTURAL EMPLOYMENT

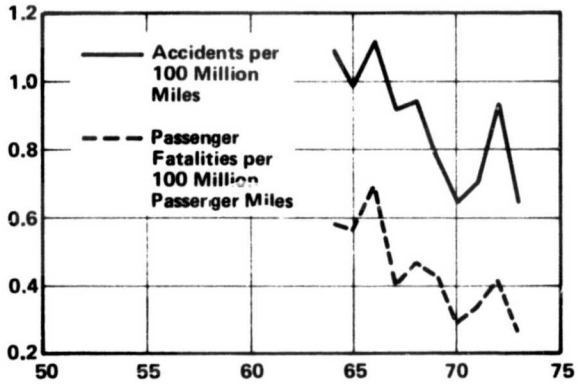


FIGURE A.5 ACCIDENTS

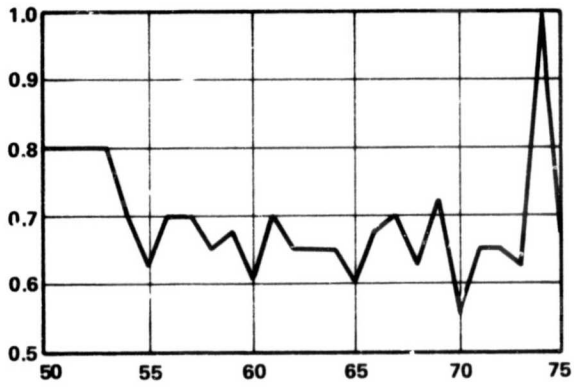


FIGURE A.4 FARM RESIDENTIAL STRUCTURE

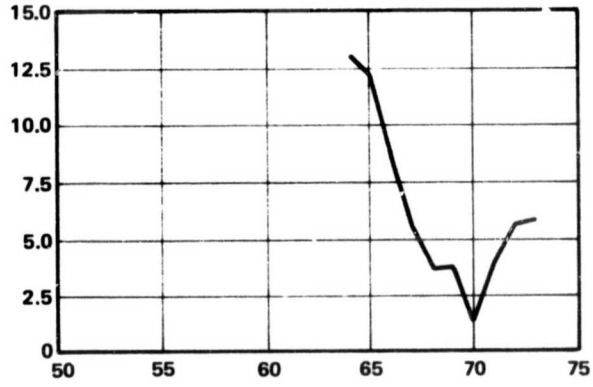


FIGURE A.6 AIRLINE INDUSTRY RATE OF RETURN ON INVESTMENT

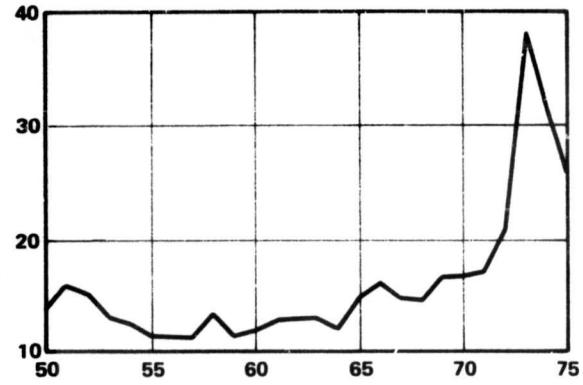


FIGURE A.7 FARM PROPRIETORS INCOME

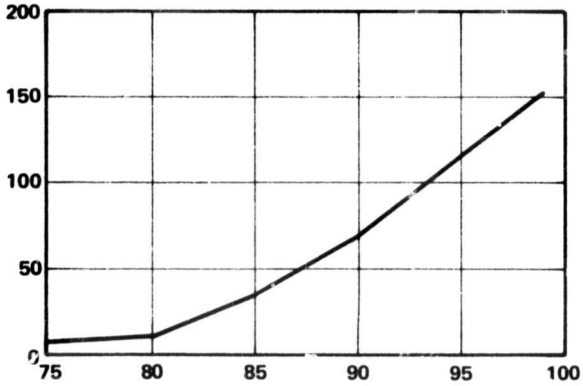


FIGURE A.8 ACRES TREATED BY AG-AIR

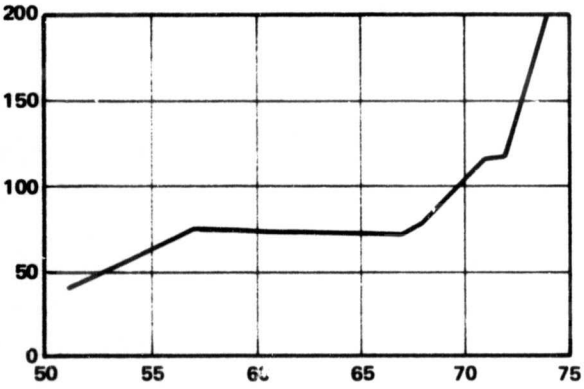


FIGURE A.9 PROJECTED ACRES NO-TILL FARMED

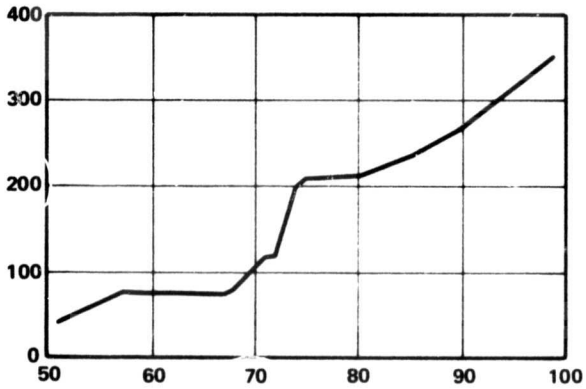


FIGURE A.10 PROJECTED ACRES TREATED BY AG-AIR